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RHIZOCTONIA CROCORUM (PERS.) DC. AND R. SOLANI KÜHN (CORTICIUM VAGUM B. & C.), WITH NOTES ON OTHER SPECIES

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The form genus *Rhizoctonia* was established in 1815 to include two parasitic species, both characterized in part by the production of a mat of violet mycelium investing the affected roots or other submerged members. The serious root diseases due to these organisms (later included in one species) have received consideration by many mycologists since that time. The demonstration is comparatively recent, however, that several important types of root and certain stem and other diseases of a variety of hosts are induced by two or more related species of this genus.

The literature of Rhizoctonia diseases has grown enormously in the past fifteen years, yet some unnecessary confusion and difference of opinion exist regarding the two main species or groups of species and their distribution and relation to disease in plants. This is in part due to the lack of comparative study and to the neglect or inadequacy of herbarium material. It seems well, therefore, to present a conspectus of the investigations relating to this subject, and to include such comparative data as are available.

In coöperation with Mr. F. C. Stewart of the New York (Geneva) Agricultural Experiment Station, I undertook, in 1898, a general study of the relation of *Rhizoctonia* to plant diseases in America. This joint investigation followed two

independent studies, one of a serious root disease of the sugar beet, the other of a destructive stem rot of the carnation. A preliminary report upon the investigations relating to *R. Solani* Kühn was published ('01), and it was arranged that in the further work one of us would undertake the morphological, cultural, and taxonomic aspects of the study, and that the other would assume responsibility for all cross inoculation and field work. Unfortunately for this purpose a change of position on the part of one of us and the demands of other work necessitated the abandonment of the plan as proposed. It is to be regretted particularly that the systematic inoculation experiments which had been carried forward for two seasons could not be continued and published. It is understood, however, that an extensive study in the relations of the culturable forms on different hosts has been carried forward both by cultural and inoculation experiments at the University of Illinois by Dr. George L. Peltier, who has already presented a preliminary report ('15), on the subject. It is mainly a general account of the diseases with notes on comparative morphology that I am able to include, but it is hoped that this may serve to clear up the more obvious difficulties and to suggest some problems requiring special investigation.

The writer wishes to acknowledge the assistance, mentioned in the text, of many mycologists who have furnished material during the progress of these studies, and especially the coöperation of Mr. F. C. Stewart, who contributed many of the American hosts during the earlier studies. To Prof. E. A. Burt I am also indebted for suggestions.

THE VIOLET ROOT FELT FUNGUS, RHIZOCTONIA CROCORUM (PERS.) DC.

EARLY PATHOLOGICAL STUDIES

The first mention of a plant disease which may be referred with certainty to *Rhizoctonia* as the causal agent is an important paper by Du Hamel (1728) read before the Paris Academy. In this paper he gives a careful description of a fungous disease of *Crocus sativus* (saffron) occurring in France. His description of general pathological features

leaves little to be desired, and one cannot mistake the fact that he was discussing the disease, later known to be due to *Rhizoctonia Crocorum*. He does not describe the more minute morphological features, but discusses the macroscopic appearance of the mycelium and sclerotial stages with such completeness that no doubt remains concerning the identity of the fungus. The illustration included would likewise confirm the description. He regarded the sclerotium, "tubercule," as the fruit body of a fungus allied to the truffles, and to this special form of body, assumed to bear the organs of reproduction, he gave the name "tuberoides." He likewise determined that a similar fungus is the cause of a disease found upon the roots of *Sambucus Ebulus, Coronilla varia, Ononis spinosa, Muscari* sp., and perhaps other plants.

It was more than fifty years later that Fougeroux de Bondaroy (1785), discussing primarily a disease of the saffron known as "tacon" gives further notes on the "mort du safran," recording the occurrence of this disease on asparagus when following (in the same soil) diseased crocus.

After a further considerable lapse of time De Candolle (1815) made a careful study of the pathology of a similar alfalfa (*Medicago sativa*) disease in the vicinity of Montpellier, but known throughout France. This led to the establishment of the genus *Rhizoctonia* as noted later. It is necessary to the pathological account to note here, however, that he recognized two species, *R. Crocorum* DC., primarily inhabiting the crocus, and *R. Medicaginis* DC., on the alfalfa and other hosts. He did not follow the development of the fungus on the saffron, where host characteristics render somewhat obscure the appearance of the fungus; and so for a long time the continuous violet felt of mycelium was associated primarily with *R. Medicaginis*.

Among other diseases of the carrot and beets in Germany, Kühn ('58) found typical rots of these root crops, accompanied in both cases by a red-violet mycelium with other characteristics indicating the alfalfa organism. He identified the fungus as *R. Medicaginis* and thus established the greater importance of Rhizoctonia diseases, and greatly extended the

range of the fungus. He found a somewhat similar disease of the potato, but clearly distinguished the fungus as another species, as further indicated in another part of this paper.

Chief among those who extended our knowledge of the pathology and distribution of the violet root felt fungus was Rostrup ('86), who observed the fungus in Denmark and described its effects on various hosts.

EARLY TAXONOMIC AND MORPHOLOGICAL ACCOUNTS

The fungi belonging to the genus *Rhizoctonia* received attention taxonomically from the earliest mycologists. Brief references should be made to the works of some of those who have presented synopses of the genus or who have contributed to the solution of the problem regarding the taxonomic position of these fungi. Bulliard (1791) evidently based his description of species upon the observations and data of Du Hamel and de Bondaroy; emphasizing therefore the sclerotium as the fruit body, and believing it homologous with the truffle he gave to this fungus on *Crocus sativus* the name *Tuber parasiticum*. He contributed nothing further to the morphology of the species. Persoon (1801) did not accept Bulliard's disposition of the fungus, but named it *Sclerotium Crocorum,* and gave a diagnosis which, while based on the observations of the earlier writers, did not confuse the sclerotium with a true fruit body.

De Candolle (1815[a]), in his first taxonomic discussion employed Persoon's name for the fungus, and then, after giving the characteristics and parasitism of the species on alfalfa more careful attention, he established (1815, 1815[b]) the genus *Rhizoctonia* to include two species, *R. Crocorum* DC. on crocus and other hosts and *R. Medicaginis* DC. on alfalfa. It will be noted that he adopts Persoon's specific name for the crocus fungus. De Candolle also considers a doubtful species, *R. Mali,* reported on apple.

Nees (1816) placed the crocus fungus in *Thanatophytum* under the name *T. Crocorum.* Fries (1823) assigns *Rhizoctonia* to the *Sclerotiaceae* just following his extensive genus *Sclerotium.* It is important to note, since Fries' work has been

made the starting point for mycological nomenclature, that he designates three species in the following order, (1) *R. Crocorum* DC., (2) *R. Medicaginis* DC., and (3) *R. muscorum* Fr., also giving *R. Mali* DC. among *species ignota.* The descriptions of the two species first mentioned leave no doubt that he is here defining the violet root felt fungus of crocus and of alfalfa. Moreover, Fries recognized *Sclerotium Crocorum* Pers. as a synonym of *R. Crocorum* DC. So far as has been ascertained no specimens of these species which he examined are still in existence. Link (1824) excluded the doubtful forms, added a species *R. strobilina,* and otherwise left the genus as constituted by De Candolle. Duby (1830) included among the species *Rhizoctonia Allii* Graves, arranging the genus close to *Sclerotium* in the *Scleroteae* of *Lycoperdaceae.* Fries later included in this genus *R. Batatas* Fr. on *Ipomoea Batatas* from America.

The most complete mycological account of the genus *Rhizoctonia* is that given by L. and C. Tulasne ('62). They reduce *R. Crocorum* DC. and *R. Medicaginis* DC. to a single species to which they apply a new name, significant of the appearance of the fungus, *R. violacea* Tul. This reduction to a single form was made after a most careful morphological study of the fungus in all stages. From the accurate descriptions and the excellent illustrations it is clear that they had under consideration material referable to the names above. The Tulasne brothers also refer to other species insufficiently known, as follows: *R. Allii* Graves, *R. Batatas* Fr., and *R.* (?) *Mali* DC. They were inclined to the view that the affinities of the genus would be found to be with the *Ascomycetes,* and, in fact, they considered certain minute cushions of hyphae, referred to in detail later, as immature perithecia. Successively, therefore, attention was drawn by mycologists (1) to the sclerotium as a fruit body (Du Hamel and Bulliard), (2) to the sclerotium as a sterile structure (Persoon), (3) to the strand-like habit of the mycelium (De Candolle), and (4) to the minute cushion-like sclerotia as suggesting perithecia (Tulasne, L. and C.).

NAME, SYNONYMY, AND MATERIAL EXAMINED

Since the investigations of the brothers Tulasne many mycologists have studied the violet root felt fungus on its various hosts, especially on crocus, alfalfa, and certain root crops. There is general, though not complete, agreement in confirmation of the view that the crocus and the alfalfa forms are identical, and that this species, *R. Crocorum,* occurs on numerous hosts. I shall indicate later some of the morphological details in which the two forms agree and give other evidence supporting the view of a single species. For the present it is necessary to anticipate this evidence in order to state that until a perfect stage is definitely established, it would appear that the correct designation of the violet fungus is *Rhizoctonia Crocorum* (Pers.) DC. As noted above, the specific name applied by Persoon was adopted by De Candolle when he established the genus. This name, perhaps unfortunately, has priority over *R. Medicaginis* DC. in that it is mentioned first by Fries (1823). Though necessary, it may seem unwise to call the fungus *R. Crocorum,* inasmuch as it is far more widely distributed on alfalfa; and, furthermore, because its dicotyledonous hosts are more numerous. *R. violacea* would be a most appropriate descriptive name, but it is obvious that this also would not conform to the rules. The following provisional synonymy has been collated:

Tuber parasiticum Bull. (1791),
Sclerotium Crocorum Pers. (1801),
Rhizoctonia Crocorum DC. (1815),
Rhizoctonia Medicaginis DC. (1815),
Thanatophytum Crocorum Nees. (1816),
Tuber Croci Duby (1830),
Rhizoctonia Rubiae Dcne. (1837),
Rhizoctonia Dauci Rabenh. (1859),
Rhizoctonia violacea Tul. (1862),
Rhizoctonia Asparagi Fckl. [non Fr.] (1869),
Hypochnus violaceus Eriks. (1913).

The identity of *Rhizoctonia Crocorum* DC. and *R. Medicaginis* DC. suggested by the brothers Tulasne ('62) and accepted by most taxonomists, has been confirmed by a study

of all the material I have been able to examine, and there is included below a list of the material identified as *Rhizoctonia Crocorum* (Pers.) DC.

Exsiccati: *Rhizoctonia Medicaginis* DC., Linhart, Fung. Hung. Fasc. 4: *400; Rhizoctonia Dauci* Rabenh., Rabenhorst, Herb. Mycolog. Fasc. 1: *74.* (*Helminthosporium rhizoctonum* Rabenh.); *Rhizoctonia Solani* Kühn, De Thuemen, Myc. Univ. Cent. 18 : *1797.*

European collections: (1) Material from Prof. Delacroix, Paris, 1901, as follows: on sugar beet; on sugar beet, obtained by inoculation from diseased beet; on potato; on potato, by inoculation from affected beet; on crocus; on crocus, by inoculation from affected beet; on alfalfa; on *Onobrychis sativus;* on asparagus; and on asparagus, by inoculation from diseased beet. (2) On crocus from bulb gardens, Pithiviers, France, 1901. (3) From Prof. Aderhold, Proskau, Germany, 1899, on carrot and on root of young apple tree. (4) From Prof. Sorauer, Berlin, 1900, on potato and on asparagus. (5) From Herr Weigand, Helmitzheim, Bavaria, 1899, on alfalfa. (6) From Prof. v. Tubeuf, Munich, 1899, on sugar beet. (7) From Prof. Hartig, Munich, on roots of young conifer. (8) From Prof. Cugini, Modena, Italy, 1899, on alfalfa. (9) Material which the writer was able to obtain fresh near Munich, 1905, on sugar beet and alfalfa.

In 1901 the writer was unable to find in the Kew Herbarium or in Paris any type material, and none was found in Montpellier in 1905.

American collections: (1) From Mr. P. W. Graff, Manhattan, Kansas, 1911, on alfalfa. (2) From Mr. F. D. Bailey, Laurel, Oregon, (sent by Dr. G. L. Peltier, Univ. of Ill.) 1915, on potato.

DISTRIBUTION

In Europe the violet root felt fungus is in general widely distributed, but its occurrence now and then in epidemic form on some one host would appear to indicate some locality or race influence. On *Crocus sativus* the fungus has been reported from France chiefly; on asparagus, more frequently from France, Belgium, and Italy; on *Medicago sativa* it would

seem to occur more commonly from southern France eastward to Bavaria and Hungary and southward to the Mediterranean. No information is available with respect to its occurrence in Russia. On the fleshy root crops and on the potato the fungus has often been reported from central France and Germany northward through Denmark, Norway and Sweden, and also on the sugar beet in Italy. In Denmark it appears to be found oftener on species of *Trifolium* than on alfalfa.

The root felt disease is certainly not unknown to market gardeners and others throughout England, yet there are relatively few references to it in pathological literature. It would appear that Güssow has observed the fungus in England, for in speaking of diseased tubers from a farm in Essex he says, "They were covered with a dull reddish-brown webbing, which was raised into numerous points, as if grains of sand were below it," but in view of his reference in the same article to the commoner potato fungus no definite statement should be made. Salmon's account ('08) of the disease of seakale, described as "a felted mass of violet spawn or mycelium," evidently refers to this species.

In the United States *R. Crocorum* was first reported from Nebraska by Webber ('90) on lucerne. He states that it was rare in the Nebraska flora at that time. Heald ('06) lists the fungus as among disease-producing organisms prevalent in Nebraska during 1905. The record is as follows: "Root rot. *Rhizoctonia violacea* Tul. reported from a single locality: Platte County. Not common in that region." The complete observations made in 1906 were not reported until later, in which account, however, Heald ('11) fails to make note of Webber's earlier report of its occurrence. Freeman ('08) refers to the fungus as the cause of a well established disease of alfalfa in Kansas, and a specimen received by the writer in 1911 from that state indicates that it is identical with the European fungus. More recently it has been mentioned by Gandara ('10), and the inference is that it is found on alfalfa in Mexico. The first occurrence on potato in America is from a locality in Oregon (Bailey, '15). No well authenticated instance of the occurrence of this fungus in South America,

Australia, Asia, or Africa has come to my attention, yet the distribution of alfalfa growing throughout the world and the frequent interchange of seed might suggest that the distribution of the organism may be found to be much more general than is reported. It should be mentioned that Shaw ('13) reports the fungus from India, but he has obviously been misled regarding the fungus concerned, as will be shown later.

Du Hamel represented the violet root fungus as prevailing under a variety of soil conditions, but electing dry, gravelly, and acid localities. It is reported by the brothers Tulasne that while wet weather may give the fungus an advantage, still it is found in the driest situations permitting crop growth. In central Germany Kühn's studies led to the suggestion that on root crops and potatoes it is found more frequently in low and stagnant places. Frank and Comes concur in this view. The writer was able to observe the fungus in the vicinity of Munich in 1905 and in the fields examined, it was found under conditions which appeared to be favorable for the growth of the host. The very general occurrence of the fungus in southern Europe, especially in southern France and Italy, would seem to indicate that excessive moisture is not always an important factor. At the same time the fungus is of frequent occurrence in Scandinavia. It is not reported as one of the more serious diseases of any host in England. In the more humid regions of the eastern United States it is unknown, while two of the localities from which it has been reported are regions of lower humidity and lesser rainfall.

HOST PLANTS AND GENERAL SYMPTOMS

There is every reason to believe that the number of host plants for *Rhizoctonia Crocorum* is much greater than has been reported. The fungus has been observed upon many economic plants; and it has been reported in the agricultural press of Europe as occurring upon a variety of weeds, but these references are not always definite. Eriksson has made some observations regarding the plants attacked when culti-

vated in soil from a carrot field known to be infected, and the following weed hosts are noted: *Stellaria media, Myosotis arvensis, Galeopsis Tetrahit, Erysimum cheiranthoides, Urtica dioica.*

This would indicate that a careful study of any epidemic would confirm the view that the number of hosts is considerable. The following is a list by families of the host plants which have been reported in the more accessible literature:

Pinaceae
- Abies pectinata
- Picea alba
- Picea excelsor
- Pinus Laricio
- Pinus montana

Liliaceae
- Asparagus officinalis
- Crocus sativus
- Lilium sp.
- Muscari sp.
- Narcissus sp.
- Tulipa sp.

Urticaceae
- Ficus silvatica
- Humulus Lupulus
- Urtica dioica

Polygonaceae
- Rumex crispus

Chenopodiaceae
- Beta vulgaris
- Chenopodium album

Caryophyllaceae
- Spergula arvensis
- Stellaria media

Cruciferae
- Brassica campestris
- Brassica Rapa
- Crambe maritima

Rosaceae
- Crataegus oxyacantha
- Pyrus Malus

Leguminosae
- Anthyllis vulneraria
- Coronilla varia
- Medicago lupulina
- Medicago sativa
- Melilotus alba

Leguminosae
- Onobrychis sativa
- Ononis spinosa
- Ornithopus sativus
- Phaseolus sp.
- Trifolium hybridum
- Trifolium pratense
- Trifolium repens
- Vicia Faba

Geraniaceae
- Geranium pusillum

Rutaceae
- Citrus Aurantium

Vitaceae
- Vitis sp.

Umbelliferae
- Daucus Carota
- Erysimum cheiranthoides
- Foeniculum vulgare
- Pastinaca sativa

Oleaceae
- Ligustrum vulgare

Convolvulaceae
- Convolvulus arvensis

Boraginaceae
- Myosotis arvensis

Labiatae
- Galeopsis Tetrahit

Solanaceae
- Solanum tuberosum

Rubiaceae
- Rubia tinctoria

Caprifoliaceae
- Sambucus Ebulus

Compositae
- Taraxacum officinale
- Sonchus arvensis
- Sonchus oleraceus

The difficulty in giving an accurate list of hosts compiled from the literature is, however, a serious one, since one cannot be certain that all the observations are carefully made. Again, some mycologists do not distinguish the two species of *Rhizoctonia* here discussed; thus Salmon ('08), after describing an interesting disease of seakale with all the characteristics of *R. Crocorum,* goes on to refer to carnation stem rot, damping off, and other diseases as if they were induced by the same fungus, doubtless, however, intended to have reference to another related fungus.

Regarding the above-ground symptoms of affected plants, it may be said that they are not striking, and were it not for the characteristic dead area in the field it would not be an easy matter to designate slightly affected plants. Generally, there is in alfalfa evidence of yellowing, sometimes marked chlorosis, while in beets and carrots there is merely a paler appearance of the foliage, followed by wilting. The critical period for affected alfalfa is usually about the time of the second cutting, and at this time considerable wilting may occur without preliminary indications of lack of health. In these main effects the disease is remarkably similar to the Texas root rot of cotton, alfalfa, and other plants. The unmistakable symptom is the relatively sudden dying of the plant affected.

The disease is generally though not necessarily fatal. Even a plant so susceptible as the alfalfa may recover from early injuries, usually with the loss of the tap root. Under certain conditions the disease incites the development of adventitious roots,—which may be a factor in recovery. The progress of the disease in the field is radial, and during the first year especially, circular dead areas mark its presence. The spread of the fungus during the season may be from a few feet to several rods. After the first year or two, considerable areas irregular in outline may be involved.

MYCELIUM AND SCLEROTIA

It would be difficult to confuse the mycelium of the violet root felt fungus with any other species, for when one is

familiar with it in the different stages of development it is at all times an organism with striking characteristics. Such differences in appearance as may be found in comparable stages on the various hosts may be regarded as causally related to the host substratum, or, at least they may be so regarded until adequate morphological differences or contrasting physiological relations are established. The general appearance of affected roots of asparagus, carrot, beet, or alfalfa are well expressed in some of the common names applied, such as red root, root felt disease, violet fungus, etc.

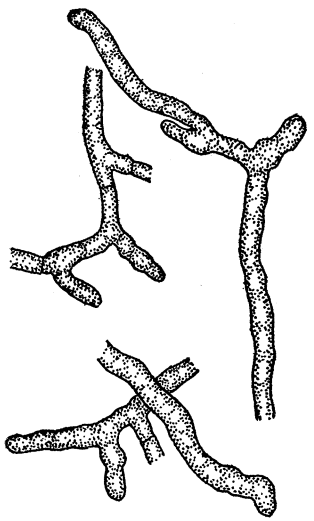

Fig. 1. *Rhizoctonia Crocorum:* Young hyphae.

With sufficient time for abundant growth the fungus completely invests the root or root system with a mantle, weft, or mat of hyphae of characteristic color. In the early stages of growth on the root the mycelium is pale buff to violaceous, but when the root is completely invested, the mycelium is red-violet to violet-brown, and always violet-brown with age or when densely matted. The numerous small darker papillae or "minute sclerotia" in the mantle of mycelium are in reality cushion-like mycelial bodies described later.

In the following description the writer will not attempt to follow all changes in the development of the various mycelial conditions, but will endeavor to give briefly those developmental features of greatest interest and those diagnostic characteristics which may be applied to most herbarium material. For further morphological details the accounts of L. and C. Tulasne ('62) and Prillieux ('91) should be consulted.

The external, general hyphae are more or less different in form and appearance with age. The younger hyphae are usually dilutely violaceous with a pigment which may be decolorized by the application of acidulated water. The pro-

toplasm is dense towards the tips of branches and vacuolated farther away. The hyphae are somewhat flexuous, branched (sometimes closely), with the branches arising at right angles to the main hypha, and with a partition wall laid down at not over 10 μ distant (fig. 1). With age the hyphae become rigid, somewhat less in diameter, 4–8 μ, the branching is distant, and these branches readily break off at the first partition wall (fig. 2). At the point of union the diameter is uniform with the main hypha. The partition walls are distant,

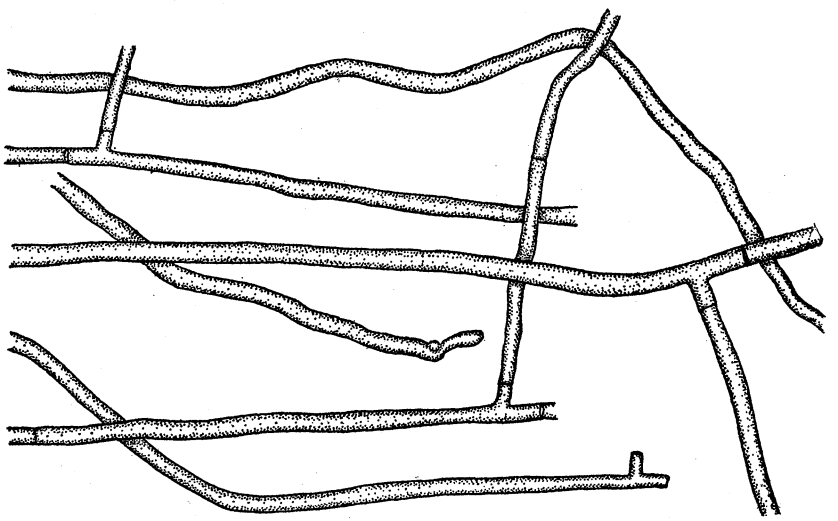

Fig. 2. *Rhizoctonia Crocorum:* Mature root-investing hyphae.

often 120–200 μ apart. The walls now possess the violet-brown pigment and in the lumen little or no protoplasm is observable.

The internal mycelium is likewise branched, septate, often associated into loose strands, passing between the cells or traversing them. In the early stages of the disease, so far as reported, these internal hyphae are nearly colorless; Prunet reports that there are sometimes areas of brown mycelium in the attacked tissues, and this I find particularly true of asparagus. The internal hyphae are generally of less diameter than those constituting the external mat.

Disregarding for the time the small cushions already men-

tioned, the hyphae constituting the external mantle may be uniformly distributed, as is the case usually when the fungus attacks fleshy roots or tubers, or they may also form a number of aggregates having the appearance of loose or root-like strands. The strands are developed later rather than early in the progress of the disease. They are conspicuous on such hosts as alfalfa and sainfoin. These strands course along the whole root system; they also pass out into the soil, apparently beyond the minutest rootlets, and doubtless attack plants in the vicinity. Upon the larger strands sclerotia may be formed, and thus the sclerotia are connected with the mantle of hyphae.

Infection Cushions.—Small stromatic bodies distributed amongst the hyphae were noted by several of the early observers. Kühn ('58) calls special attention to them on the carrot and the potato. The brothers Tulasne ('62) studied and described them in some detail and came to the conclusion that these were the early stages in the development of the perithecial form. Search for the reproductive phase was in this way transferred from the sclerotium to the bodies in question. Sorauer ('86) among others accepted the view of the perithecial nature of this structure. Prillieux ('91) seems to have been the first to point out that the "corps miliaires," as he termed them, are in reality special mycelial cushions having the important function of effecting the penetration of the host. He regarded them as the main, if not the sole, seats of tissue invasion, and his studies included a comparison of these bodies and of the penetrating strands in alfalfa, sugar beet, and crocus. After mentioning these cushions as one type of sclerotia, Prunet designates them more specifically as minute "corps noirâtres," .2 to 1.2 mm. in diameter with a brown hyphal cortex and a colorless medullar. He indicates that these as well as the larger sclerotia send out filaments which enter the soil and extend the fungus. These bodies have also been figured by Bailey ('15) in the case of the occurrence of the fungus on the potato in Oregon and particularly well by Salmon and Crompton ('08, pl. 25). The writer is of the opinion that Prillieux's notion is in general correct,

and while they are not the only means of penetration they are most important in this connection.

The hosts upon which the writer has had the opportunity to examine the infection cushions in best condition are alfalfa, carrot, and asparagus. The cushions are distributed over infected roots, often 1 mm. apart in alfalfa, .5 mm. in carrot, and 3 mm. in asparagus. The external hyphae are for the most part similar to those of the general mycelium, but there occur also branches in which the cells are short and swollen, sometimes resembling a short chain of spores. This form of hypha may have given the suggestion of a conidial stage (see Kühn ('58), Sorauer ('86), and others. The medullary portion of younger cushions is made up of finer, almost colorless hyphae, and it is this type which enters—strand-like—the cortical tissues of the root, destroying particularly the cambium and younger phloem regions. In the later stages of development it will be found that the cushions seem to extend considerably into the cortex, and more of the hyphae are colored.

In this connection it is well to call attention briefly to some gross changes in the affected roots. By the time the host (alfalfa) reaches the critical stage, the bark slips readily from the root. The disintegration may continue further, however, through the spread of the fungus to the medullary rays and all other parenchyma, so that the root shreds or crumbles when lifted. The late stages of destruction may be assisted by saprophytic organisms. It is difficult to determine if the fungus continues its growth for a short time after the death of the root. At any rate, the fungus rapidly disappears with the further decay of the roots.

In the case of asparagus the cushions are largely superficial and the main affected tissues are beneath the shell of thick-walled cells constituting the periphery of the host. In the carrot the invading strands are large, and the host cells in the vicinity rapidly collapse and darken. I have been fortunate in obtaining affected asparagus roots at intervals after the disease had run its course. In no case could any evidences of spore forms be found which gave promise of genetic connection. On the contrary, the fungus gradually disappears,

first the mantle of mycelium, and then the cushions, so that when the root is reduced to a mere shell there are only vestiges of the cushions remaining.

Sclerotia.—The true sclerotia are flattened or rounded bodies varying in diameter from a few millimeters to several centimeters. When mature they are of a deep violet-brown

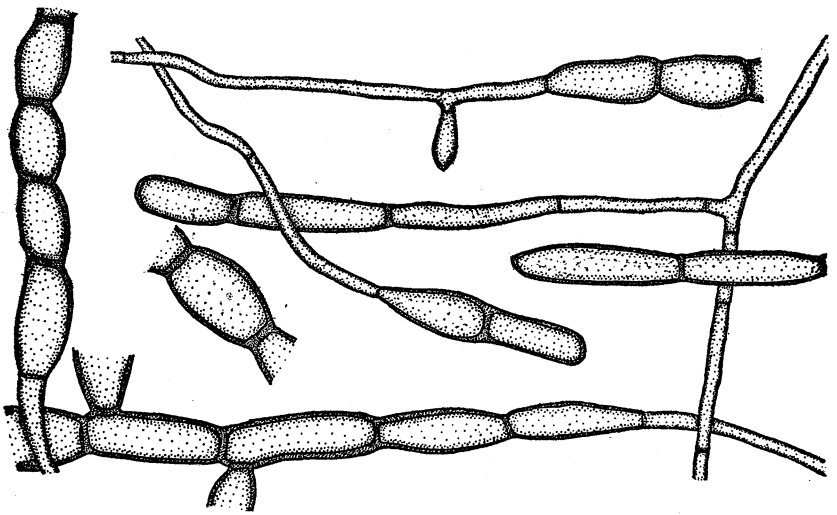

Fig. 3. *Rhizoctonia Crocorum:* Cells characteristic of the tufted growth covering the surfaces of the large sclerotia and to a certain extent of the "infection cushions."

and are thickly clothed with a persistent velvety felt, externally of the same color as the root-investing hyphae, but darkening further in. Among the surface hyphae of the sclerotia as well as of the "infection cushions" are found chains of enlarged cells (fig. 3) quite distinct from the enlarged cells of *R. Solani.* The sclerotia, as noted previously, are always connected with the root felt by large hyphal strands. In the saffron disease the sclerotia are formed both in contact with the shriveling bulb and also in the adjacent soil. On affected alfalfa roots they often occur below, and in the angles of, the larger branches, but often one finds no sclerotia in immediate contact with the host. In connection with diseased carrots, beets, and potatoes, they are not so frequent, unless perhaps they are then formed at greater

distances from the plant. Most herbarium material, unfortunately, with the exception of crocus specimens, does not include sclerotia.

In section a sclerotium consists of fairly compact tissue made up of cells often considerably branched and sometimes curiously lobed (fig. 4).

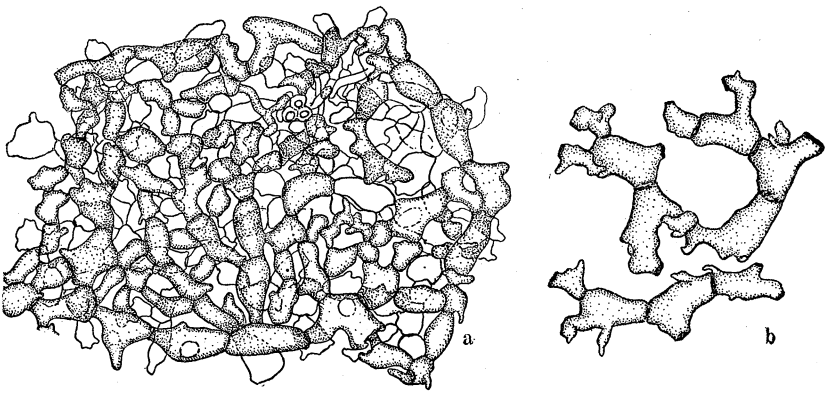

Fig. 4. *Rhizoctonia Crocorum:* a, from a section of a large sclerotium; b, extreme forms of cells isolated from a macerated sclerotium.

SUGGESTIONS REGARDING THE PERFECT STAGE

It has been noted that Du Hamel and other early observers stated that the affinities of the violet fungus were with the truffles. Persoon, Fries, and others placed the genus near *Sclerotium.* Tulasne considered the small sclerotia as probably a stage in the development of an ascomycete (pyrenomycete). This suggestion of Tulasne has apparently influenced many mycologists, and a search in this direction for the perfect stage has continued practically until the present time. Fuckel suggested that *Lanosa nivalis* Fr. might be considered the first or conidial stage of this fungus and he believed that the minute sclerotia or penetration cushions gave rise during the latter part of the season to pycnidia. With the more complete disintegration of the affected tissues he reported the development of a perithecial stage, and this fungus he called *Byssothecium circinans* (*Leptosphaeria circinans* (Fckl.) Sacc., *Trematosphaeria circinans* (Fckl.) Wint.). It will be noted that Winter regarded this

view of the genetic relation to *Rhizoctonia* as improbable; and Saccardo, who at first accepted the relationship, subsequently changed his opinion. Prunet ('93) states that he made certain inoculation experiments from which he was convinced that Fuckel was correct; but we possess no indications as to how these experiments were conducted. The writer in 1899, at Leipzig, germinated the spores of *Leptosphaeria circinans* and obtained a mycelium bearing no resemblance to the Rhizoctonia hyphae. The idea that *Leptosphaeria* constitutes a perfect stage of the *Rhizoctonia* has had no support recently, although Comes ('91) incorporates it in an extreme form in his treatment of the genus.

Rostrup ('86) found in the spring on the old roots of affected plants a pycnidial stage which he considered to be connected with the Rhizoctonia hyphae; and on the old roots of *Ligustrum* he found reddish filaments and scattering perithecia; the latter he identified as a species of *Trichosphaeria.* His assumption, however, has received no encouragement. When Hartig ('80) discovered a *Rosellinia* as the perfect stage of his *Rhizoctonia Quercina* there was a temporary revival of interest in the quest for one of the *Ascomycetes* as the perfect stage of *R. Crocorum.*

Frank ('97) reported observing the violet fungus on the grape, and associated with it he found a species of the *Thelephoraceae.* This he regarded as the perfect stage, and to the fungus he applied the name *Thelephora Rhizoctoniae.* This observation has failed of confirmation.

Eriksson ('13) has recently presented an extension of his earlier account ('03[a]) of diseases produced by *Rhizoctonia,* and in this he records a new "*Hypochnus,*" *H. violaceus* (Tul.) Eriks. as the perfect stage of "*Rhizoctonia violacea,* Tul." In this he was stimulated by the observations of Rolfs ('03) and others in America, and Pethybridge ('11) in Ireland, on the occurrence of the basidial stage (*Corticium vagum* B. & C. or *Hypochnus Solani* Prill. & Del.) of *Rhizoctonia Solani* Kühn, resulting in a reëxamination of some material of the violet fungus on roots and stems of certain wild plants. This material had been preserved in alcohol thirteen

years earlier. The result of his study is reported as follows:

> "D'après ces renseignements, il faut—du moins pour ce qui concerne les formes du champignon qui envahissent les Carrottes—considérer comme résolue la question tant débattue de savoir à quel groupe rapporter le mycélium stérile connu sous le nom de *Rhizoctonia violacea.* Dans ce qui suit, je vais indiquer le nom scientifique qu'il faut donner, ainsi que les caractères diagnostiques du champignon autant que j'aie pu en juger sur les documents conservés que j'avais à ma disposition."

On the basis of these observations he creates the *Hypochnus* mentioned. No adequate diagnosis is given, but the important part of the account is as follows:

> "Ensuite le champignon forme autour des tiges de la même plante ou d'autres espèces de plantes immèdiatement au-dessus du sol, une enveloppe annulaire, membraneuse, d'un rose tendre, qui, montant souvent sur les tiges jusquà une hauteur de 5 à 15 mm. et s'étalant parfois sur la surface du sol comme une feuille toute mince, produit des basidiospores. C'est le stade *Hypochnus.*"

This apparently refers to material on *Stellaria media, Myosotis arvensis, Galeopsis Tetrahit, Erysimum cheiranthoides, Urtica dioica,* and *Sonchus arvensis,* which hosts he would regard as harboring the Hypochnus stage of that form of the violet fungus attacking the carrot, and for this reason the names just given appear in the list of hosts.

In the writer's opinion he properly considers it remarkable that the fructification stage should attack hosts other than those producing the sterile stage. In view of the character of the material, the incompleteness of the account, and the possibility of confusion with *Corticium vagum* B. & C. it would appear necessary to await confirmation of the observation that a *Corticium* (*Hypochnus*) may represent the perfect stage of the fungus here discussed, although, reasoning from the apparent relationship of this species to *R. Solani,* a Corticium stage might well be assumed. The writer has been unable thus far to secure any of the material mentioned.

In a footnote Eriksson expresses himself thus: "Quant à la Rhizoctone de la Luzerne, je suis porté à croire, d'après les

observations de cette année (1912), quelle doit être rapportée à un groupe d'Ascomycètes." This suggestion is both interesting and surprising since Eriksson adopts the Tulasnes' name for the *Rhizoctonia* on carrot and this would seem to concede the identity of the carrot and alfalfa forms. It is also in a measure inconsistent with his inoculation results, as reported later.[1]

CROSS INOCULATION AND CULTURAL STUDIES

The amount of cross inoculation work yet reported is not considerable, and for this, doubtless, the inability to cultivate the organism is largely responsible. Throughout the early literature numerous indications are offered showing that following a severe outbreak of the disease on any crop, it may appear on susceptible plants grown in the affected area—observations which tend to establish the identity of the fungus on different hosts. Among later observations may be mentioned those of Güntz ('99) who records that in a field where alfalfa and red clover had been seriously affected, beans, potatoes, and tuberous artichokes were planted; the potatoes subsequently developed the disease in serious form, and the other plants showed indications of its presence. In England it is reported (Bd. of Agr., '06) that potatoes are affected by the violet felt fungus, especially when following alfalfa; and under similar conditions the fungus appears upon clover, carrots, beets, and mangolds.

Eriksson ('13) undertook some cross inoculation work employing, in zinc cylinders, soil from diseased carrot fields (eight cylinders) in contrast with soil taken from areas free from the disease (two cylinders). At the same time, to the diseased soil he added pieces of carrots affected by the fungus. The cylinders were permitted to stand over winter

[1] Since obtaining proof of this paper I have received from Prof. Eriksson an advance reprint of his paper, "Fortgesetze Studien über Rhizoctonia violacea DC." Arkiv för Bot. **14** (Art 12) : 1–31. *f. 1–13.* 1915. It is impracticable to include here a full discussion of this paper. It is necessary to state, however, that he treats at length *Rhizoctonia Medicaginis* DC. and *R. Asparagi* Fckl., and includes inoculation experiments indicating form differences. After germinating the spores of *Leptosphaeria circinans* he comes to the conclusion that, in spite of his earlier work on *Hypochnus violaceus,* the pyrenomycete mentioned is the perfect stage of *R. Medicaginis.* Prof. Eriksson has also furnished material of *R. Asparagi* and of the *Leptosphaeria.*

and the following spring were planted to several varieties of carrots, to beets, mangolds, red clover, and alfalfa. At the time of harvest, the carrots were all more or less severely affected, while the sugar beets and alfalfa showed very light attacks, and the clover none at all. Continuing the work in subsequent seasons he obtained evidence in one case—that of the sugar beet—pointing to an increased virulence of the fungus with adjustment to that host. On the contrary, in the second year the alfalfa exhibited greater resistance, thus rendering a decision as to the existence of physiological races hazardous. He also reported, that on placing diseased soil and diseased carrots in a box in which various weeds were permitted to grow, the fungus appeared on eight species of weeds (representing several families), apparently a considerable proportion of those present. This also would seem to discourage the idea of marked host specialization.

Attempts to cultivate the violet fungus on artificial media have been made by several investigators without success. While in Leipzig, 1900, I obtained particularly good material on alfalfa from Bavaria. Dilution cultures were attempted both on various kinds of agar and on gelatin, but no growth of the fungus was secured in any case. Further trials were made with material from France in 1902, and again upon receiving comparatively fresh material from Kansas in 1911. Bailey ('15) reports an endeavor to cultivate the organism in Oregon, also without success. It is quite possible that special conditions are essential to its growth in artificial culture, but we should not assume that it is incapable of growth in this way. It would appear that the presence of contaminating organisms is not the sole cause of the difficulty, since isolated hyphae in the dilution cultures remain free from the growth of contaminating organisms, and yet themselves fail to develop a colony of growth. It will be recalled that Atkinson[1] found difficulty, but ultimate success, in growing *Ozonium omnivorum* (Lk.) Shear, the cause of the southwestern root rot of cotton. The writer also found that this organism is not readily cultured, but obtained a satisfactory

[1] Bot. Gaz. **18**: 16–19. 1893.

growth on cotton decoction starch paste in 1902. Since in general pathology and physiology the cotton *Ozonium* and the violet *Rhizoctonia* have much in common, a further careful investigation of their life relations would doubtless yield interesting results.

PREVENTION AND CONTROL

Relief measures respecting the violet fungus are very largely limited to the practices of good culture, good drainage, and sanitation. The early pathologists have generally recommended pulling up diseased plants and burning them. It is well to point out, however, that after a careful examination of the distribution of the fungus on the smallest fibrous roots, it has been found to invest these to a considerable depth in the case of alfalfa, and therefore a very small measure of security may be expected unless one carries out this recommendation in a far more thorough manner than is practicable in the field. The further suggestion has been made that where the diseased areas are few, small, and clearly defined, trenches may be dug to prevent the further spread of the disease; but if this should prove feasible under any conditions, it would be advisable only in connection with a thorough disinfection of the isolated areas by formaldehyde or sulphuric acid—the former disappearing from soil in time, and the latter being easily neutralized by liming. The rotation of crops is undoubtedly desirable, but complete immunity from the disease cannot be expected if we may trust the statements of Du Hamel and other observers to the effect that the fungus may remain alive in the soil for periods of from three to twenty years. The fact that many hosts are affected also complicates the practice of rotation.

THE COMMON RHIZOCTONIA, R. SOLANI KÜHN (CORTICIUM VAGUM B. & C.)

EARLY STAGES

In addition to his discussion of the violet *Rhizoctonia* on beets and carrots Kühn ('58) described a disease of potatoes, of which the causal organism was recognized as a species of

Rhizoctonia differing notably from the violet organism, and to this potato fungus he gave the name *R. Solani.* The life history of the fungus and the symptoms of the disease induced were very imperfectly known at the time, so that the description could not be complete. As a result, those who subsequently discussed the genus *Rhizoctonia* have sometimes recognized *R. Solani,* while others have referred the organism to *R. Crocorum* (*R. violacea*), and still others have assumed that *R. Solani* Kühn was also the cause of another disease of beets and of carrots mentioned by Kühn without identifying the causal organisms. After a study of certain diseases in America induced by *Rhizoctonia,* I was keenly aware of this confusion, so when opportunity presented itself in the winter of 1899–1900 I conferred with Professor Kühn regarding those diseases, and also endeavored to obtain satisfactory specimens of the fungi. There has been no earlier opportunity to utilize the information obtained in connection with a general discussion of the genus.

Kühn laid special stress upon a scab ("Schorf oder Grind," later termed "Pockenkrankheit") of potatoes, sometimes followed by deeper seated injuries and decomposition ("als Räude und Krätze bezeichnet"). The symptoms are clearly those that we now know as one type (cf. McAlpine, '12) of the potato diseases ascribed to *R. Solani* Kühn (*Corticium vagum* B. & C.). It has been noted that the fungus was not so well described as might be wished, and the spores mentioned were evidently those of contaminating organisms, or else the oval cells of the tufted stage of the fungus; but when we use in connection with this general description Kühn's comparison of this plant with the violet fungus (Kühn, '58, p. 248) it is convincing that the fungus on the potato which he had under consideration was not *Rhizoctonia Crocorum.*

The sclerotia were also inadequately described and figured. With reference to that point, however, Professor Kühn stated that while a common form of the fungus on the tubers consisted of irregular superficial sclerotia, this form did not lead to serious consequences and therefore received less attention from him. Material of this superficial sclerotial stage was

furnished the writer by Professor Sorauer in 1900 (for a photograph see Duggar, '09, p. 477, fig. 219), and, subsequently, from other points in Germany. It is clearly the "black speck" form of the disease now generally recognized. Professor Kühn also identified cultures of the American fungus on sugar beets (Duggar, '99) as very close to, if not identical with, his *R. Solani.* In 1858 Kühn was obviously unaware of the fact that the violet fungus also occurs on potato in Germany; and, in fact, he told me in 1900 that it was subsequent to 1858 when he first collected specimens of the violet fungus on this host. "The violet fungus produces no serious epidemics of the potato in Germany," he declared. Professor Kühn was unable to locate type material of *R. Solani,* and such material is doubtless unavailable. Before presenting still other indications pointing unmistakably to their identity, I shall proceed on the basis that it is correct to refer the sterile stages of the commoner American *Rhizoctonia* on potato and other plants to *R. Solani* Kühn, and once studied comparatively there can be no confusion of this plant with *R. Crocorum* (Pers.) DC.

A disease of carrots was also described by Kühn with which no fungus was positively associated. The indications are insufficient to determine whether this was a fungus or a bacterial disease. So far as the writer is aware no disease of carrots in Europe due to *R. Solani* has since been reported, though in 1900 Professor Kühn stated as his opinion that carrots as well as beets in Germany were affected by a fungus similar to *R. Solani.*

The violet root felt fungus was clearly distinguished by Kühn ('58, see pp. 235–237, 243–249) in its occurrence on both beets and carrots. It is not possible to mistake his statements in which the organism on these hosts is referred to *Rhizoctonia Medicaginis* DC." Moreover, he nowhere suggests the combinations *R. Dauci* Kühn and *R. Betae* Kühn, which later crept into the literature of the subject. This fact makes it difficult to understand the nomenclature employed by Eidam ('87) and Comes ('91). In discussing a beet disease prevalent in Germany, Eidam refers the organism to *Rhizoctonia Betae* Kühn. He gives a description of the disease and of the fun-

gus, including its growth on culture media. It is clearly the beet disease now well known in America, and of which the causal fungus is referred to *R. Solani.*

Kühn did describe the symptoms of another disease of beets, and this last bears every indication of being the heart rot later known to be due to *Phoma Betae* (*Phyllosticta tabifica*), much discussed by Frank and others. Kühn's discussion of this other beet disease has been interpreted, also, in the way I have indicated by Prillieux and Delacroix ('91) and others outside of Germany. In my conference with him, Professor Kühn stated that the only Rhizoctonia diseases of beets and carrots which he knew in the vicinity of Halle in 1858 and earlier were those due to the violet fungus, and of these he exhibited specimens having the usual characteristics. From the evidence at hand, therefore, the Rhizoctonia disease of beets described by Eidam was new on that host. It would seem, then, that Eidam is the authority for the combination *R. Betae,* which he attributes to Kühn. In any case it becomes a synonym of *R. Solani* Kühn (*Corticium vagum* B. & C.).

In discussing the Rhizoctonia disease of potatoes in Europe Sorauer ('86) describes unmistakably the "black speck" or sclerotial form of the fungus, and while he, like many others, assumed that it would be found to belong among the *Ascomycetes,* it is obvious that the characteristics of this stage of Kühn's fungus were well recognized.

Among the forms of *Rhizoctonia* which he enumerated and discussed Comes ('91) includes *R. Dauci* Kühn, and *R. Betae* Kühn. In his discussion of the first-named he reviews Kühn's account of the violet fungus on carrots, already mentioned; but in the account of *R. Betae* Kühn he evidently refers both to Kühn's account of the heart rot of beets and to the Rhizoctonia disease of this host described by Eidam. Pammel ('91) was the first American pathologist to report in this country a disease now known to be caused by *R. Solani.* He, however, followed Comes and Eidam in referring to the fungus causing the beet rot as *R. Betae* Kühn.

Atkinson ('92, '95) studied a "sterile" fungus causing sore

shin or damping off in cotton, and ascertained that the same fungus was commonly associated with, and capable of, inducing damping off of various seedlings in the greenhouse.

Duggar ('99) also referred to the beet rot fungus in America as *Rhizoctonia Betae* Kühn, following Comes, and was able to determine that this beet fungus was identical morphologically (mycelium and sclerotia) with the damping off fungus found by Atkinson. The characteristics of the two organisms in culture were also identical, both forming on certain media a rich mycelium and finally numerous flaky or tufted centers of growth, some of which become irregular, often crust-like, sclerotia. Neither on affected seedlings nor on beets were sclerotia ordinarily produced (compare, however, Edson, '15, pl. 23).

Subsequently, Duggar and Stewart ('01) reported that several types of disease, on a variety of hosts, including the potato, were induced by *Rhizoctonia.* The account given was intended to be merely preliminary, and for this reason a few words of explanation are necessary. The account referred to did not (perhaps unfortunately) explicitly indicate that, as far as the studies had progressed, there was evidence that the organism, or forms of the organism (except in the case of the form on rhubarb, referred to later) exhibited morphologically and in culture the characters of the beet rot and damping off fungus. The authors were likewise convinced, after a study of European material of Kühn's fungus on the potato, of the identity of the American and European forms on this host. Cultural studies were being carried forward with *Rhizoctonia Solani* from many hosts, since there was the possibility of establishing definite forms or races, of finding the perfect stage, and of discovering other species. Again, specimens of the violet root felt fungus on various hosts had been obtained by one of us, and it was intended to include in a final paper a general account of the genus.

This failure to designate the form with which we worked has doubtless led to some misunderstanding (see Prillieux '97, Eriksson '13, p. 17). However, in a more recent account (Duggar, '09, pp. 477–478), it will be seen that the diseases

discussed are ascribed to *R. Solani* (*Corticium vagum* B. & C.).

DISTRIBUTION

Rhizoctonia Solani is distributed throughout the United States and Canada. There is every reason to believe that it exists as a saprophyte in most arable soils, and under certain conditions may attack many species of plants. It is perhaps most frequently noted as a damping off disease in greenhouses and seed beds, but this occurrence may be explained by the fact that here the conditions are probably more conducive to the pathogenicity of the fungus. On the potato it is likewise wide-spread, although, as noted later, the economic importance of the diseases induced varies in different sections of the country, probably in accordance with climatic and soil conditions. In all potato-producing states and regions it is a well-known disease. On the sugar beet it has been observed in many states. The fact that it is an important disease of one crop or another in every section of the country is alone sufficient indication of its general occurrence. *Rhizoctonia* has been mentioned in Brazil by Potel ('00), but it is not clear to which species he refers.

It is rather surprising to find that *R. Solani* has received relatively little attention in Europe. Although recognized as inducing a disease of the potato widely distributed in central Europe, and occasionally reported on the beet, yet little careful work has been bestowed upon the fungus. Eriksson ('13), seems to be unfamiliar with the fungus in Sweden. On this account we can gain no incidental information regarding *R. Solani* as a result of his extensive studies of the related species in that country. The following will express his attitude regarding *R. Solani:*

> "Il paraît très douteux, du moins si l'on en juge d'après les descriptions et les figures données, que les nouvelles formes de la Rhizoctone stérile signalées dans ces derniers temps par B. M. Duggar et F. C. Stewart sur une quantité de plantes différentes en Amérique (* * *) soient vraiment identiques aux formes du *Rhizoctonia violacea* qui ravage l'Europe."

We have very little data regarding its occurrence in other sections of continental Europe, although from conference

with Prof. Delacroix in Paris (Nov. 28, 1901) and from an examination of material furnished by him I learned that it is not uncommon throughout France on the potato. It will be recalled that the perfect stage was described by Prillieux and Delacroix ('91). Judging from the amount of the black speck disease observed on the potato in the markets of various cities in southern Europe during 1905–'06 the writer would infer that it is of more frequent occurrence than is reported. Pethybridge ('11) finds the fungus (including the Corticium stage) well distributed in Ireland, and it is reported from other parts of Great Britain.

McAlpine ('11) has reported this fungus on the potato from several points in Australia, and he states that it occurs upon a variety of economic plants. Since it has proved a serious disease in very few localities, it receives little attention, and is therefore freely disseminated by commercial intercourse. It is also known in New Zealand and Japan.

The investigations of Shaw ('13) suggest that *Rhizoctonia Solani* may be an important disease-inducing organism in some of the more humid regions of India. Reference is made later (pp. 448–450) to the fact that he has obviously misapplied this name, however, and also that other confusion has resulted. In spite of this, it seems certain that he has observed all stages of the fungus.

TYPES OF DISEASES INDUCED, SYMPTOMS

It is not my purpose to attempt a complete description of the more important diseases caused by this species, yet sufficient will be included to indicate the main types of diseases thus far investigated, their general distribution, and their striking pathological relations. By types of disease, I have reference to general effects or symptoms. The effect of the fungus upon the stems may occasion a different appearance from its action upon the root, and thus there arise the different types referred to. With respect to penetration and action upon the cell the behavior of the fungus may be the same in all cases. Moreover, as a result of the primary injury, secondary effects may occur, and sometimes such secondary phe-

nomena may be so striking in appearance as to dominate the primary injuries or lesions.

For convenience we may arrange the types of disease in the following categories: (1) damping off, (2) stem rot, (3) root rot, (4) leaf rot, (5) scab, and (6) such secondary effects as rosette, little potato, and leaf roll. Since more than one type of disease may occur upon a single host, and especially since one form of the disease may grade into another, it will be more practicable to discuss these under the following captions: (1) damping off, (2) potato diseases, (3) rot of fleshy roots, (4) stem and root rots of herbaceous plants, and (5) fruit and leaf injuries.

DAMPING OFF

It would appear that the first mention of a disease of seedlings caused by *Rhizoctonia* is that of beets, recorded by Eidam ('87), although he gives no complete account of the evidence. It is preferable to date our knowledge of damping off diseases caused by *Rhizoctonia* from the work of Atkinson ('92), who studied particularly sore shin of cotton, but he also found the "sterile" fungus to cause damping off of seedling beets, radish, lettuce, egg plants, cabbage, and other plants in the forcing house. The later identification of the fungus concerned (Duggar, '99) and its association with the damping off of various plants (Duggar and Stewart, '01) was only the beginning of the observations which have now served to direct our attention to the vast importance of this fungous disease throughout the United States both in the greenhouse and in the outside seed bed.

Among numerous instances in which damping off has been reported due (or in all probability due) to this fungus may be noted the following: (1). It has been found as a source of serious injury to ginseng in the seed bed (Van Hook, '04; Whetzel and Rosenbaum, '12). (2). Tobacco seedlings are so frequently injured that soil treatment has received special consideration in the case of this crop (Selby, '04; Cook and Horne, '05). (3). As a damping off disease of cotton (sore shin) it occurs not only in America but in Africa (Balls, '05, '06) and possibly in India (Shaw, '13) as well. (4). Tomato

seedlings seldom attacked by *Pythium* have been found to succumb to *Rhizoctonia* in Louisiana (Edgerton and Moreland, '13). (5). Alfalfa seedlings have been reported susceptible in one instance (Stewart, French, and Wilson, '08). (6). Seedlings of various species of conifers from a few days to nine weeks old have been reported attacked in several instances (Hartley, '12, Clinton, '13).

The majority of the instances reported above were under normal seed bed or field conditions. Many other cases of the damping off of seedlings might be included where seeds are grown in crowded condition in moist greenhouses. Again, damping off of cuttings by *Rhizoctonia* is now a well-known phenomenon in the propagating house, and special precautions are taken with respect to drainage and moisture in order to reduce the injuries to a minimum. It is safe to assume—since the fungus seems to be found in practically all soils—that it is in general the worst enemy of seedling plants. In fact, it may be anticipated that under conditions favorable for the fungus the damping off of seedlings of numerous species may be anticipated. So far as the writer has been able to ascertain there has been no report of the damping off of monocotyledonous plants under normal seed bed conditions.

While *Rhizoctonia Solani* may perhaps induce damping off in innumerable species regarding which observations are lacking, some of the host plants which have come to the writer's attention as particularly susceptible are the following: lettuce (*Lactuca sativa*), celery (*Apium graveolens*), beet (*Beta vulgaris*), cress (*Lepidium sativum*), tobacco (*Nicotiana Tabacum*), balsam (*Impatiens balsamina*), snapdragon (*Antirrhinum majus*), cotton (*Gossypium* spp.), cucumber (*Cucumis sativus*), squash (*Cucurbita* spp.), sunflower (*Helianthus annuus*), carrot (*Daucus Carota*), radish (*Raphanus sativus*), and phlox (*Phlox Drummondii*).

Since the phycomycetous damping off fungus *Pythium* has been known to pathologists much longer, and prior to 1895 was practically the only fungus to which this type of disease was ascribed, it is probable that much damage due to *Rhizoctonia* has been ascribed to *Pythium*. Moreover, unless

examined microscopically, there are no symptomatic differences between the effects of the two organisms.

Seedlings affected exhibit symptoms somewhat different with age. The youngest seedlings of all delicate plants show what may be called the usual damping off characteristics. Near the base of the stem an hygrophorus or translucent appearance is quickly followed by shrinkage of the tissues and weakness of the stem. The plants topple over, the fungus invades all parts, and spreads rapidly to the neighboring individuals. The cells of the sap-perfused tissues are flaccid and injured, some showing this even before the entrance of the hyphae into the cells. Somewhat older plants and the more robust seedlings of cotton, bean, etc., often exhibit characteristic lesions. Atkinson ('95) gives a description of its effect on cotton seedlings as follows:

> "The trouble is caused by the fungus growing first in the superficial tissues of the stem near the ground and disintegrating them before it passes to the deeper tissues; in other words the fungus never seems to penetrate far in the living tissues, but 'kills as it goes,' and the tissues become brown, depressed, and present the appearance of the plant having a deep and ugly ulcer at the surface of the ground. The fungus does not spread into the tissues either above or below the ulcer to any extent, but literally eats away at that point until it has severed the stem at the affected place or the plant has recovered from its effects."

DISEASES OF POTATOES

The potato is the most interesting of the host plants with respect to the parasitism of *Rhizoctonia* by reason of the many types of disease induced under diverse conditions. The conditions may be in part climatic and, in part perhaps, dependent upon the pathogenicity of the particular strain of the fungus or upon the stage and development of the host at the time of infection. It has been noted that when Kühn first described the disease of potatoes in Germany he laid emphasis upon a scab which was often followed or accompanied by decay. This form of the disease was probably less prevalent in the country as a whole at that time, and the more recent accounts indicate that the "black speck scab" or "black speck," properly the sclerotial stage, is the feature by which the main type

of the disease is now generally known. At present the following main types of injury are recognized for the potato: (1) black speck scab or sclerotial stage, (2) Rhizoctonia scab, (3) Rhizoctonia rot, (4) stem lesions and root rot, (5) rosette and leaf roll, and (6) little potato and aerial potato.

Black speck is a form of the disease most widely distributed and in itself scarcely merits consideration as a "disease" at all, since the sclerotia are superficial on the tuber, and it is merely the appearance of the potato which is affected. The sclerotia may lead to other types of disease which are more serious. The black specks show up most clearly when the potatoes are wet and it is only at this time that they present the appearance of being black, for, as indicated later, the normal color of the sclerotia is deep brown. It was this form of the disease which first gave evidence of the wide distribution of the fungus in America (Duggar and Stewart, '01), and it has been shown to exist in practically all potato-producing sections of the United States and Canada. It occurs throughout Europe, especially on the later varieties of potatoes. It is also reported from India, Africa, and Australia, so that it may be assumed to be world-wide in its distribution on this host. It is safe to say that this is the only form of the disease which does not result directly in serious injury and loss to the crop. In the United States, especially from Ohio westward, other forms of the potato disease assume a seriousness nowhere else attained. If all such forms of the disease mentioned below occur in the Atlantic states they are of little consequence. They are, moreover, far less frequent in Europe, India, and Australia.

The Rhizoctonia scab is believed to occur as a result of the penetration of hyphae during the early stages of sclerotial development, and occasionally it may be induced by a late growth of new hyphae from old sclerotia. The writer has had an opportunity of examining only casually this form of the disease. It is one of the types doubtless seen by Kühn. According to McAlpine ('11), when this disease occurs, practically every part of the tuber is affected, no normal skin remaining. In severe cases the scab areas may be thrown into folds or puckers and these rub off easily in the form of "cork dust."

It is reported that the irritating hyphae are then found at the bases of such scab formations. This scab has been reported fairly common in Europe and in Australia. Güssow ('05) seems to refer to the same type in England, and Rolfs ('03) describes it from Colorado. Specific scabs of the potato have been clearly defined and related to particular organisms. The capacity of the tuber to respond with cork formation to varied injuries suggests that in certain modifications of Rhizoctonia scab this fungus may accompany other active scab inducing agents.

The Rhizoctonia rot is a form of disease which appears relatively late in the season when certain conditions prevail, or possibly when the fungus has for one reason or another developed unusual virulence. The disease is supposed to originate either from stem infections, from sclerotia, or from scab areas. In any case penetration of the mycelium occurs to a considerable depth, and according to McAlpine ('11) there is produced in Tasmania a form of the disease known as brown rust, characterized in the early stages by dark spots in the tuber resembling certain symptoms of *Phytophthora*. It may also be associated more or less with the deeper form of the Rhizoctonia scab. During the latter part of the season a typical stem rot may occur which is not characterized by the definite lesions described later. Instead, the affected cortex slips readily from the wood and about the bark a considerable web of the yellow-brown hyphae may be found superficially, below and just at the surface of the ground, and the pith may be fairly stuffed with the mycelium. Plants only slightly affected with this form of the disease, especially when growing on rich garden or muck soil, have been found to yield the collar or *Corticium* stage.

It is not always easy to distinguish as separate forms of the disease, stem lesions, rosette, little potato, aerial potato, rolling, etc., for these types of injury are often associated. All of these types except stem lesions are properly secondary effects, and there is abundant evidence that all represent responses of the plant to disturbed condition or nutrition, sometimes associated with native weakness. It would not be

strange, therefore, if somewhat similar effects should characterize, as they do, purely "physiological" disturbances. Stem lesions are generally dark, sunken areas, clearly different from black leg, occurring at the surface of the ground or on any of the underground stems, or tuber-forming stolons. These lesions may result in the early death of the affected plants. Selby ('02, '03) maintains that generally the lesions upon young shoots are associated with stunted growth and the production of rosette-like clusters of the upper leaves, as well as with less marked modifications of habit, including slight leaf rolling. Drayton ('15) finds the hyphae in the lesions.

If the tuber-bearing stolons are the seat of injury, the food supply is cut off from the young tubers and there may result "little potato," a form of the disease which Rolfs ('04) has found to be an important cause of the potato failures in Colorado. Little potato in Australia is considered an evidence of underground injuries occurring late in the season. Injuries which effectually girdle the stem, especially if these occur during a moist season or when the crop is frequently irrigated, lead to the formation of aerial tubers. In the relation of *Rhizoctonia* to the various types of potato diseases much remains to be investigated, and Orton ('14) rightly suggests that inadequate attention has been bestowed upon the question of the predisposition of the tubers used as seed, since it is quite possible that these may yield offspring with tendencies toward rosetting, leaf rolling, and other morphological modifications.

ROT OF FLESHY ROOTS

The root rot of beet, apparently first described by Eidam ('87) in Germany, and shortly afterward found by Pammel ('91) in Iowa, was observed in New York (Duggar, '99) some years later. Since that time it has appeared epidemically in Nebraska (Lyon and Wianco, '02) and other western states. The fungus is most virulent during midsummer or later. Infection may take place at the bases of the leaves or on the fleshy root. The leaf bases blacken, the leaves become paler, and finally wilt. Pammel ('91) has drawn attention to the

fact that when fleshy root crops of this type are attacked by such fungi they die gradually, while herbaceous plants (cotton, alfalfa, etc.) wilt suddenly. This is probably closely related to the effect of the fungus on the conducting tissues. In the beet root the invaded tissues are pale brown, and often cracks or rifts occur, though rotting may take place without such lesions. Sometimes there is partial recovery after the cracks are formed, and in this case callous tissue is developed.

A soft crown rot of the radish induced by this fungus has apparently been reported only once (Duggar and Stewart, '01). A similar disease of the carrot was found in 1900 in New York and this is possibly the disease first reported by Kühn ('58, pp. 241–243), although he did not identify it as due to a *Rhizoctonia*.

STEM AND ROOT ROTS OF HERBACEOUS PLANTS

Rhizoctonia Solani produces serious stem and root rots of a number of economic herbaceous plants, among which the following are known to be important: carnation (*Dianthus caryophyllus*), Sweet William (*Dianthus barbatus*), bean (*Phaseolus vulgaris*), sweet-pea (*Lathyrus odoratus*), and violet (*Viola odorata*).

The carnation stem rot is one of the most destructive diseases occurring on this host and is wide-spread in the United States. The general symptoms of the disease on carnation and Sweet William are much the same. The stem is affected at or just below the soil level. The fungus penetrates and kills the cortex which may be readily slipped from the wood. Through the medullary rays the hyphae also enter the pith, which likewise decays. In later stages of the disease the wood shreds, due to the complete penetration by the fungus of all parenchymatic tissues.

Several important epidemics of *Rhizoctonia* on bean have been reported from different parts of the United States. In addition to the outbreak described by Duggar and Stewart ('01), Hedgcock ('04), a few years later, found the bean disease severe near St. Louis. The base of the stem and the larger roots bore characteristic ulcerations; pods were af-

fected, and through the sunken areas of these the hyphae penetrated the seed and produced small sclerotia on the seed-coats. The fungus was cultivated and typical Rhizoctonia hyphae and sclerotia were obtained. Fulton ('08) observed the disease in Louisiana on stems and pods, with the characteristic ulcerations, especially at the surface of the soil or just below. He proved the causal relation of the organism through cultures, and inoculations yielded positive results with the damping off of seedlings. McCready ('10) reported the bean disease as new to Ontario, where it was also characterized by stem and pod ulcers. In New York Barrus ('10) observed an epidemic of this host in which as many as 30 per cent of the plants were affected. He determined the fungus by cultural studies and proved its pathogenicity by inoculation. On the sweet-pea the disease is mainly a root rot, yet the base of the stem may also be considerably affected before the plant succumbs. On the violet it is primarily a crown disease, but where the plants are succulent and the conditions are moist, the leaves are considerably invaded.

FRUIT AND LEAF INJURIES

In discussing stem diseases the occurrence of *Rhizoctonia* on bean pods has been mentioned. Another case of fruit injury is described by Wolf ('14), who found a severe rot of egg plant fruits from which the fungus was obtained. The pathogenicity of the organism was determined by inoculations, and cross inoculation from tomato and potato led to the conviction that the organism was *Rhizoctonia Solani.*

Direct attacks of leaves by *Rhizoctonia Solani* are infrequent. From the habits of the fungus this would be expected. The one serious leaf disease reported is that of lettuce (Stone and Smith, '00), in which the fungus spreads over the whole surface, causing a moist rot. Sclerotia are frequently formed in connection with this affection. It would be anticipated, perhaps, that diseases of a similar nature might be found on other plants with the rosette habit. Leaf stalks are frequently invaded, or may be the regions of first attack, in the case of the beet disease. The disease of leaf stalks of rhubarb

reported by Duggar and Stewart ('01) is not due to typical *R. Solani.*

MYCELIUM AND SCLEROTIA

The morphological characteristics of the hyphae and sclerotia have been adequately described by several writers, but it may be well to summarize some of the more important features. Upon such hosts as the potato, sugar beet, carnation, and others there is more or less development of an external web, but never over the general root system such a complete investment of roots by a mantle of hyphae as characterizes the violet fungus. The external hyphae are somewhat colored, usually yellowish brown, and they are generally of two types. One type may be designated as purely vegetative and another as constituting the external tufts or masses when these occur. All hyphae are practically colorless when young, vacuolate, more or less irregular, septate with the septa at intervals of 100–200 μ. The diameter of vegetative hyphae is 8–12 μ. Branches arise, and when young these are inclined in the direction of growth and are invariably somewhat constricted at the point of union with the main hyphae (fig. 5). As the hyphae mature and become more deeply colored they are more uniform and rigid, the distances between cross walls are greater, the constrictions where branches arise less marked, and the branches are approximately at right angles to the main hypha.

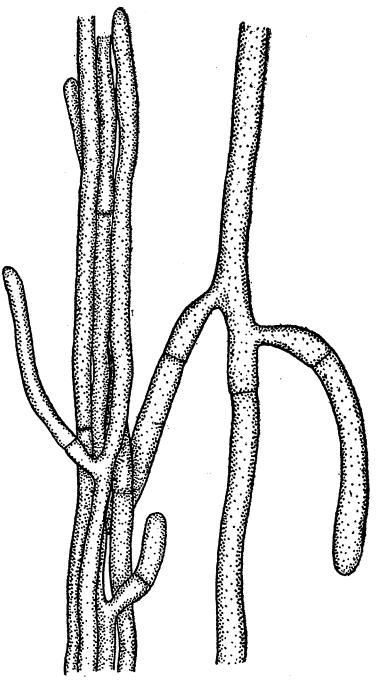

Fig. 5. *Rhizoctonia Solani* (*Corticium vagum*): A vegetative hypha and a small strand from artificial culture on potato.

On certain affected plants a short tufted or mealy growth occurs and this is made up of hyphae of very different characteristics. In the young condition threads are profusely

branched and lobed, sometimes botryoid, and they are ultimately divided into short, ovate cells, arranged in short chains, or elbowed, and producing branches in a more or less dichotomous fashion (figs. 7 and 8). In culture the denser

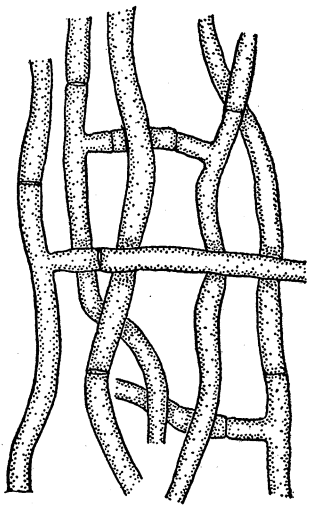

Fig. 6. *Rhizoctonia Solani:* Vegetative hyphae.

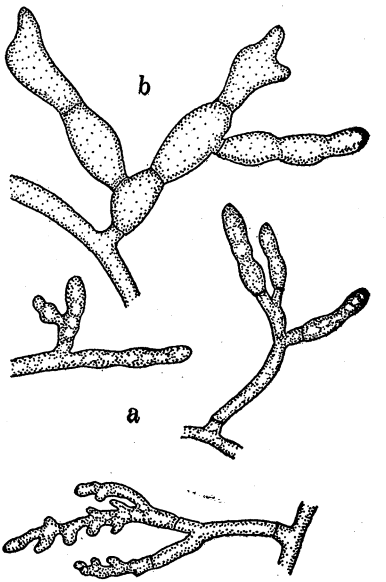

Fig. 7. *Rhizoctonia Solani:* a, young hyphae from young sclerotial tuft on lettuce; b, older cells from same source.

masses give rise to sclerotia. With maturity these hyphae become light brown in color, they break up readily into short hyphal lengths or single cells, the individuals of which bear some resemblance to conidia. However, they could not easily be mistaken for spores, although they may function as such, inasmuch as most of them may germinate within a few hours when placed under suitable conditions. I have previously described ('99) this process as follows:

> "So far as observed, germination is always by the protrusion of a tube through a septum. When several cells are connected, a germ tube from one cell may pass into and through its neighbor, * * * *, and thus peculiar appearances may result. Some of the cells of the hyphal chains seem to be devoid of protoplasm, and from neighboring protoplasmic cells the germ

tubes seem to pass into such empty cells as readily as directly into the nutrient solution. When the germ tube is from 10 μ to 20 μ in length, it is invariably narrowed towards the outlet from the parent cell, and a septum forms at a short distance from this outlet."

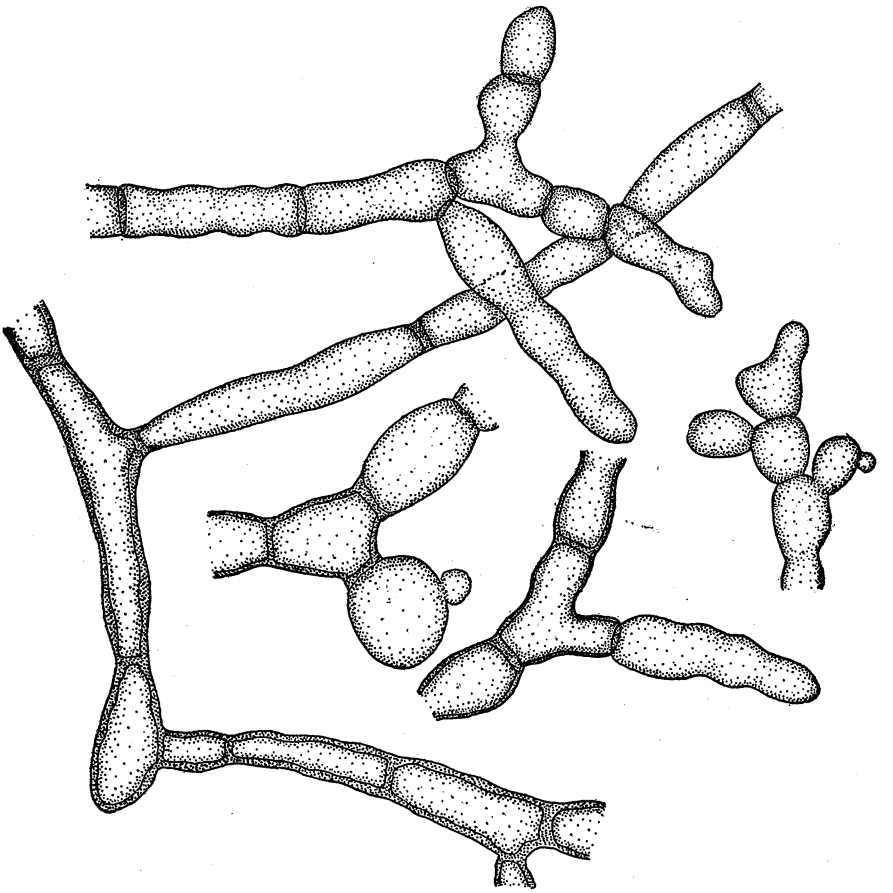

Fig. 8. *Rhizoctonia Solani:* Lobulate, moniliform, and elbowed cells from tufted growth in artificial culture.

The hyphae which penetrate the tissues remain colorless so long as they are in active growth, and while generally less in diameter they present much the same appearance as the young external hyphae. In the different strains which have been studied, originating from different hosts, certain minor modifications of the general habit of the fungus in culture have been observed. But these have not seemed to be suffi-

cient to be considered of specific importance, except in the case of the form on the rhubarb. In general, the differences referred to consist in a variable amount of the mealy or tufted growth, or of the amount of aerial growth; differences in the color of the colony are also observable; and the rapidity with which sclerotia are formed are all minor distinguishing features. The subject needs further investigation, but in general it is felt that these differences are such as might be due to permanent differences in the pathological strains, on the one hand, or may be regarded as temporary differences due to the recent environment, on the other. It may be pointed out that the appearance of the mycelium of the beet fungus from the damping off seedlings is not exactly comparable with that of the mycelium derived from the beet rot. When the organisms from both sources are grown in culture they are found to be identical. Strains do occur, however, evidence of which may persist for some time in the general appearance of the cultures.

The exact conditions under which sclerotia may occur on the various hosts affected have not been determined. It has been noted that affected potato tubers are the main seats of sclerotia formation when the fungus attacks that host. Upon this plant they are typical, and the numerous illustrations published are sufficient evidence that the appearance is much the same under a variety of conditions. Special attention may be called to the illustrations of Duggar and Stewart ('01), Rolfs ('02), Duggar ('09), McAlpine ('11), Pethybridge ('11), and Morse and Shapovalow ('14). On the majority of hosts, however, sclerotial formation is relatively rare.

From the various illustrations referred to it will be seen that the sclerotia vary in size from those so minute as to be scarcely visible, to others which may be a centimeter or two in diameter. They are generally more or less flattened, irregular, deep chestnut-brown, and generally smooth on the surface (that is, free from a looser growth of investing hyphae). Smoothness of sclerotia, which has been regarded by Kühn as of much diagnostic value, should not be considered

an important character except under natural conditions. Sclerotia which develop on fleshy organs in moist chambers as well as those which develop in culture show to a certain degree, a semi-persistent hyphal investment; but such investing hyphae are readily worn away, whereas in the violet fungus they are truly persistent.

Sections of the denser sclerotia exhibit a fairly homogeneous structure (fig. 9), with the cells more uniform in size and appearance than in *Rhizoctonia Crocorum.*

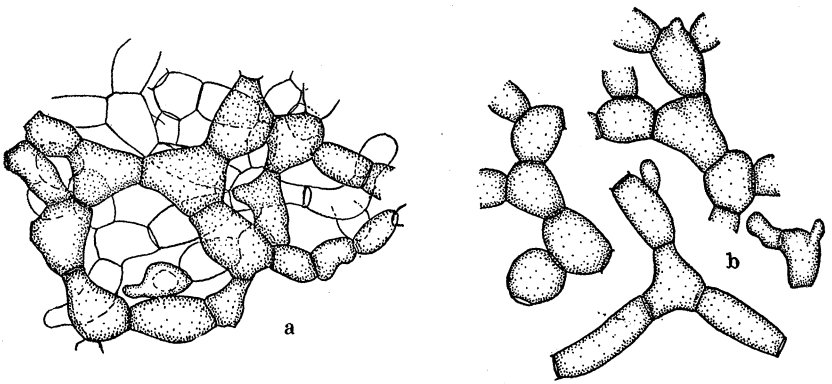

Fig. 9. *Rhizoctonia Solani:* a, from a section of sclerotium on potato; b, cells isolated by maceration of sclerotium.

THE BASIDIOSPORE STAGE, SYNONOMY, AND MATERIAL EXAMINED

Besides suggestions of a general nature no indications regarding the perfect stage of *Rhizoctonia Solani* were made prior to the discovery of the *Corticium.* Prillieux and Delacroix ('91) described *Hypochnus Solani* from potato stems, and although at this time the Rhizoctonia diseases were known in Europe no connection with this Hypochnus stage was suspected. The characteristic collar of mycelium was found surrounding the stem just above the surface of the ground, but they found nothing to indicate that the fungus had injured particularly the plant affected.

Rolfs ('03) found the collar fungus during his studies of potato diseases in Colorado. The material was determined by Prof. E. A. Burt as referable to the species *Corticium vagum* B. & C. On account of the parasitic habit, however,

it was considered advisable to make the fungus a variety of the Berkeley and Curtis species, so that it was written *Corticium vagum* B. & C. var. *Solani* Burt. Prof. Burt also recognized that it agreed closely with, and might be identical with, *Hypochnus Solani* Prill. & Del. This conclusion the writer accepts, but in view of the fact that Professor Burt is preparing a monograph of the *Thelephoraceae,* I shall not discuss this point; for the same reason I need only express doubt regarding the validity of Shaw's suggestion that *Hypochnus ochroleucus* Noack and *Corticium vagum* B. & C. are identical, although there is a certain similarity in the various stages.

Rolfs ('04) was able to germinate the basidiospores and to develop characteristic Rhizoctonia hyphae from these. Riehm ('11) also reported germinating the basidiospores and producing a characteristic Rhizoctonia mycelium together with the formation of sclerotia. Pethybridge ('15) gives a more complete account of mycelial production from spores.

The herbarium and fresh material which has been examined and found to agree with the authentic descriptions of *Rhizoctonia Solani* Kühn (*Corticium vagum* B. & C.) may be briefly enumerated:

Exsiccati: *Rhizoctonia Napaeae* nov. sp., Westendorp and Wallays, Herb. Crypt. Fasc. 5: *225.* (On decaying turnips which had been stored in a cave.)

American material: Hyphal stages on numerous hosts, many of which are mentioned in this paper, also others not included; sclerotia, on potatoes grown throughout the eastern and central United States, on potato stems (New York, 1900), on bean pods (New York, 1910), also on carnation stems, lettuce leaves, etc. Corticium stage from Prof. F. H. Rolfs, Colorado, 1901, on potato stems; from Dr. I. C. Jagger, Rochester, New York, 1914, on potato stems and on crown of carrot; from herbarium of Prof. E. A Burt, material on moist soil and decayed wood, collected by Prof. Farlow, Magnolia, Mass., 1903; from Herb. Mo. Bot. Garden, Nos. 44679, 44681, and 44682; collected by Dr. Geo. L. Peltier, Urbana, Ill., 1915.

European material: Sclerotia on potato tubers from Prof.

Sorauer, Berlin, 1900; from Prof. Magnus, Berlin, 1901; from Prof. Delacroix, Paris, 1901; and material secured on the markets of various cities, 1905–06.

As far as the writer has been able to determine, the following synonomy may be listed for *Corticium vagum* B. & C.:

Rhizoctonia Solani Kühn (1858).
Rhizoctonia Betae Eidam [non Kühn] (1887).
Rhizoctonia Napaeae West. (1846).
Rhizoctonia Rapae West. (1852).
Hypochnus Solani Prill. & Del. (1891).

PREVENTION AND CONTROL

Much the same situation confronts us regarding the prevention and control of *Rhizoctonia Solani* as in the case of *R. Crocorum.* The presence of the fungus in practically all soils serves to emphasize the importance of cultural methods including drainage and sanitation. In this case, however, since the fungus is of so much importance in the seed bed and in the greenhouse special preventive measures may be practised. Selby ('06) found that the treatment of the seed bed with formalin (1:160 to 1:200) proved satisfactory in most cases. In general, the best results have been obtained by steam sterilization, and where the facilities are at hand it is practicable to apply this to any type of greenhouse work, and, in certain cases, to seed beds outside. Liming has been recommended for the control of the disease in the field, but this has not been uniformly successful, and cultural studies have shown that the fungus is able to withstand a high percentage of alkalinity. Nevertheless, when liming results in the improvement of physical and sanitary conditions of the soil it undoubtedly assists in restraining the activity of the fungus in an indirect way, possibly by raising the resistance of the host.

Even though the fungus may be widely distributed, it is advantageous to plant clean "seed." This applies particularly to the case of the potato. The presence of the sclerotia upon the tuber makes possible the early spread of the fungus

to the young shoots. It has been positively determined that the more effective tuber treatment is the standard corrosive sublimate solution, as for potato scab. In all cases, however, it would be better to employ seed which are not infected, if this is possible.

CONCLUSIONS AND NOTES

In the account already given of *Rhizoctonia Crocorum* perhaps sufficient discussion of the occurrence and the characteristics of this form has been entered upon, except in the way of a direct comparison between this species and *R. Solani,* subsequently included. Further work upon the first named species should consider especially the culture of this organism, inoculation experiments, the development of the organism as it occurs on several hosts, the formation of sclerotia and infection cushions, and the confirmation or more definite declination of Eriksson's view that the fungus is referable to *Corticium* (*Hypochnus*). From the study of this organism thus far the following conclusions seem justified:

1. The views of L. and C. Tulasne that the forms of *Rhizoctonia* on crocus, alfalfa, and other hosts may be included in a single morphological species is confirmed.

2. The correct name of the violet root felt fungus, so long as a spore stage remains uncertain, is *Rhizoctonia Crocorum* (Pers.) DC.

3. This organism occurs throughout a considerable part of Europe and has been found in a few localities in America.

4. It attacks a variety of plants representing many families, mostly dicotyledonous.

5. The mycelium and sclerotia exhibit no important differences in equivalent stages on the different hosts, but large sclerotia which form freely in contact with crocus, and often near the affected roots of alfalfa, are seldom observed in connection with the attacks upon beets, carrots, and some other hosts.

6. The existence of distinct forms or races of this species requires further extended study.

7. The organism has not yet proved culturable with the usual laboratory methods.

8. At the present time there is insufficient evidence to determine what the perfect stage of this organism may be.

Obviously much still remains to be done regarding the physiological, pathological, and taxonomic relationship of the culturable forms which in the vegetative stage may be referred to the form-genus *Rhizoctonia*. The writer has grown in culture *Rhizoctonia* from twenty-three different American hosts, most of which are mentioned by Duggar and Stewart ('01). Most of these were grown upon a variety of culture media including prune juice, beet, and potato agar; also beans, stems and pods, celery, sugar beet and potato cylinders, and corn meal mush. With one exception (the organism from rhubarb) the cultural characteristics have been sufficiently similar, especially after protracted culture in the laboratory, to suggest a single species, with characteristics of the beet and cotton fungus, already sufficiently described (Atkinson, '92, '95; Duggar, '99). Moreover, these cultural studies have confirmed in all cases the conclusions tentatively arrived at from the preliminary microscopic examination of the fungus on the different hosts. Reasons have already been given to indicate why this species is properly *R. Solani*. It is recognized, however, that much culture and inoculation work is necessary to establish the point that the fungus on the various hosts is the same species, and to determine to what extent physiological forms may occur.

The following brief summary of conclusions may be presented with regard to *Rhizoctonia Solani:*

1. The common American species of *Rhizoctonia* is *R. Solani* Kühn.

2. This fungus is widely distributed in America and elsewhere, and would seem to occur on the potato in most regions of the world where this crop is a staple product.

3. The host plants represent many families of dicotyledons, *Asparagus Sprengeri* being the only monocotyledonous host thus far reported.

4. The types of disease induced are most diverse, damping off and root and stem rots being the most important direct effects. Secondary effects have been studied only in a few localities.

5. The mycelium and the sclerotia, as well as the general appearance on the host, readily distinguish the fungus from *Rhizoctonia Crocorum* (Pers.) DC.

6. The organism is readily culturable by the usual laboratory methods.

7. The evidence seems clear that the perfect stage of this organism is *Corticium vagum* B. & C.

It is to be regretted that the fungus causing a disease of rhubarb (Duggar and Stewart, '01) was lost before adequate study could be bestowed upon it. The fungus bore a close resemblance to *Rhizoctonia,* but the aerial hyphal cells were shorter and of greater diameter than those of *R. Solani.* No sclerotia were found on the host, and they did not develop in culture.

Shaw ('13) has contributed interesting notes on diseases of plants in India attributed to two species of *Rhizoctonia.* Unfortunately, however, he has added to the general confusion regarding this subject by a preliminary discussion which does not sufficiently designate the forms referred to, but more especially by the advancement of certain ideas regarding species which are made, apparently, without adequate study of material from other countries. The conclusions arrived at are necessarily at variance with our present knowledge of the forms of *Rhizoctonia.*

Of the organisms producing diseases in Indian crops he refers to *Rhizoctonia Solani* Kühn, a fungus which he found on jute, mulberry, cotton, groundnut, and cowpea. The mode of branching of young hyphae of his fungus is characteristic of *R. Solani,* but with this the resemblance apparently ceases. Basing an opinion wholly upon his descriptions and figures, the adult mycelium (Shaw, '13, pl. 7 and 8) differs from *R. Solani* (1) in being usually much finer; (2) in the abundant development of short "barrel-shaped" cells in the ordinary

vegetative mycelium, which would seem, from his figures, to have little in common with the chain-like, ovoidal, often branched or lobed cells (designated "barrel-shaped" by Balls) of *R. Solani* (see Atkinson, '92, '95; Balls, '05, '06; Duggar, '99; Duggar and Stewart, '01; and others); and (3) in the verrucose or warty, wall markings (Shaw, '13, pl. 8, figs. 2–3), all of which indicate some other fungus.

Again, the development of sclerotia (Shaw, '13, pl. 8, fig. 4) discloses a type of hyphal cell not characteristic of *R. Solani;* and the small discrete sclerotia themselves (Shaw, '13, pl. 2, fig. 3, pl. 8, fig. 1) convincingly indicate that another fungus was under consideration. I can find no record of a description of sclerotia resembling these in the literature of Rhizoctonia diseases. I am at a loss to understand how a fungus with such characteristics could be likened to Kühn's fungus on the potato, even though depending upon Kühn's imperfect description. On the other hand, neither in general appearance nor in structure (as described and figured by Shaw) am I able to find any resemblance to the "small sclerotia" or infection cushions of *R. Crocorum* (*R. violacea*).

In moist situations the sclerotia of *Rhizoctonia Solani* may occur on aerial organs (as on the pods of beans, Hedgcock, '04, on lettuce leaves, Stone and Smith, '00) but the frequent and apparently normal occurrence of minute sclerotia, fairly regularly arranged, on the dead tips of stems, as described by Shaw, finds no parallel in *R. Solani.* Again, in regard to the hyphae, it may be said that while there is a characteristic location of the septum when a branch is formed in a hypha of *Rhizoctonia,* this character alone is not sufficient to identify the fungus. It is necessary to take into consideration all of the mycelial characteristics which have been referred to, and if possible also the cultural characters. The writer finds that the "Rhizoctonia type" of branching is more or less similar to that found in the hyphae of certain species of *Sclerotinia, Morchella, Pleospora, Rosellinia,* and many others. It would be unwise to offer any definite suggestions regarding the fungus described by Shaw and referred to above. What relation it may bear to the fungus of "bangle blight" (Cunning-

ham, '97) must also remain, for the present, uncertain. It is possible that Shaw's fungus is one of the *Ascomycetes,* at least this is suggested by the figures of the sclerotia.

In my opinion Shaw has correctly referred to *Corticium vagum* B. & C. (accordingly to *Rhizoctonia Solani* Kühn, representing the vegetative phases of that species) another fungus which he also found in India on the groundnut and cowpea. Both the mycelium and the sclerotia of this second organism as described by him agree with *R. Solani* as we know it on carnation, beet, bean, lettuce, potato, etc., in America and elsewhere, as far as reported. The descriptions and measurements of basidia and spores are also in sufficient accord.

Shaw has even suggested that *Rhizoctonia violacea* Tul. is the vegetative stage of *Corticium vagum* B. & C. No such unfortunate confusion could result, however, had he been able to study that which is accepted as Kühn's organism on the potato together with the violet root felt fungus of Europe on any of its hosts. He has obviously failed to find material of the last named fungus in his studies thus far.

Between *Rhizoctonia Crocorum* and *R. Solani* in the vegetative condition some of the important and easily observed contrasting features as usually found are presented in the following table:

Rhizoctonia Crocorum	Rhizoctonia Solani
An external felt, or mantle, of investing hyphae, confined almost exclusively to underground organs.	External mycelium, if noticeable, only a web, or sometimes with flaky tufts, the formation of a "collar" occurring only at the time of fruiting.
Color of mycelial felt pink-red or violet to violet-brown with age.	Color of web, if evident, dirty yellow to yellow-brown.
Protoplasm of young hyphal cells soon develops a violet reddish pigment.	Young hyphal cells hyaline, and even when flavous later, pigment confined to walls.
Infection cushions conspicuous in the root-investing mycelium on most hosts.	Nothing comparable to infection cushions, though on potato sclerotia may serve as points of infection.

Sclerotia, when present, densely wooly with investing mycelium and filaments of short, ovoidal or elliptical hyphal cells. Internal structure not truly plectenchymatic, cells variable in size.	Sclerotia normally free from any definite or permanent investment of mycelium, or filaments of elbowed hyphal cells. Internal structure homogeneous in the larger, denser sclerotia.
Cultures difficult,—not yet obtained by usual methods.	Cultures readily obtained on any nutrient medium.
Typically a parasite, with perhaps the possibility of continuing existence only for a time saprophytically.	Grows rapidly saprophytically on the invaded host, and apparently on debris in the soil when conditions are favorable.

The following species may be excluded from *Rhizoctonia* as far as can be judged from reference to the descriptions and to the exsiccati material examined:

Rhizoctonia Allii Graves, de Thuemen, Myc. Univ. Fasc. 6: *600* (obviously not closely related to the forms here discussed). *R. bicolor* Ell. N. Am. Fung. Fasc. 10: *977* (with sclerotia like those of a Botrytis, e. g., *B. cinerea*). *R. Brassicarum* Lib., Libert, Pl. Crypt. Arduennae, Fasc. 3 : *240* (no characteristics of *Rhizoctonia*). *R. muscorum* Fr. Ellis, N. Am. Fung. Fasc. 13 : *1266;* Libert, Pl. Crypt. Arduennae, Fasc. 2 : *141.*

From the descriptions alone it would seem that the following species have insufficient affinities with *Rhizoctonia* to be included, but critical study of material is needed:

Rhizoctonia aurantiaca Ell. & Ev. on decaying wood of Acer; *R. Batatas* Fr. on *Ipomoea Batatas; R. placenta* Schw., and *R. radiciformis* Schw., on decaying wood (the three last mentioned are distributed in Schweinitz', Syn. N. Am. Fung., to which, however, the writer has not yet had access); *R. destruens* Tassi, reported parasitic on five species of *Delphinium,* and on *Lobelia laxiflora,* and *Hibiscus rosa-sinensis; R. moniliformis* Ell. & Ev. on branches of *Nyssa.*

Rhizoctonia Strobi Scholz ('97) on roots of *Pinus strobus* in Austria, is insufficiently described to warrant a suggestion; and *R. subepigea* Bertoni ('97) on coffee should be included in a further comparative study.

BIBLIOGRAPHY

Atkinson, G. F. ('92). Some diseases of cotton. IV. "Sore-shin," "damping off," "seedling rot." Ala. Agr. Exp. Sta., Bull. 41 : 30–39. *f. 8.* 1892.

————, ('95). Damping off. Cornell Univ. Agr. Exp. Sta., Bull. 94: 301–346. *pl. 1–6. f. 55.* 1895. [See Damping off by a sterile fungus. pp. 339–342. *f. 55.*]

————, ('02). Studies of some tree-destroying fungi. Mass. Hort. Soc., Trans. **1901:** 109–130. 1902. [See pp. 128–130.]

Bailey, F. D. ('15). Rhizoctonia violacea. Ore. Agr. Exp. Sta. Bien. Crop Pest and Hort. Rept. **2:** 252–255. *f. 26.* 1915.

Balls, W. L. ('05). Physiology of a simple parasite. Preliminary note. Khediv. Agr. Soc., Yearbook **1905:** 173–195. *pl. 6–7.* 1905.

————, ('06). Physiology of a simple parasite. Part 2. *Ibid.* **1906** : 93–99. *pl. 13–16.* 1906.

Barrus, M. F. ('10). Rhizoctonia stem rot of beans. Science, N. S. **31:** 796–797. 1910.

Bertoni, M. S. ('97). Una nueva enfermedad del cafeto. La rizoctonia. Rev. de Agron. y Cienc. Aplic., Bol. de la Escuela de Agr. Paraguay **1** : 211–223. *f. a–d.* 1897.

Board of Agr. Great Britain, Jour. ('96, '06). **2:** pp. 437–439. *f. 1–3.* 1896; **12:** pp. 667–670. *pl. 1.* 1906.

Bondaroy, Fougeroux de ('85). Mémoires sur le safran. Hist. de l'Acad. roy. de Sci. d. Paris **1782** : 89–112. 1785.

Briosi, G. ('10). Rassegna crittogamica dell 'anno 1908. Bol. del min. agr. ind. e. com., Rome. (Anno 9, vol. 1, Ser. C, Fasc. 2) : 4–14. 1910.

Brittlebank, C. C. ('13). Potato disease—the danger of importation. Dept. Agr. Victoria, Jour. **12:** 400–403. 1903.

Bubak, F. ('03). Ueber eine ungewöhnlich ausgebreitete Infection der Zuckerrübe durch Wurzelbrand. [Rhizoctonia violacea.] Zeitschr. f. Zuckerind. Böhmen **1903** : (Heft 8) : 5. pp. 1903. [Abs. in Bot. Centralbl. **93** : 193. 1903.]

Bulliard, P. (1791). Histoire des champignons de la France **1** : pp. 81–82. 1791.

Burt, E. A. ('14). Thelephoraceae of North America I. Ann. Mo. Bot. Gard. **1:** p. 190. 1914.

Butler, E. J. ('12, '13). Report of the imperial mycologist. Agr. Res. Inst. and Coll. Pusa, Rept. **1910–11** : 50–57. 1912; **1911–12** : 54–64. 1913.

Candolle, A. P. de (1815). Mémoire sur les rhizoctones, nouveau genre de champignons qui attaque les racines, des plantes et en particulier celle de la luzerne cultivée. Mém. du Mus. d'Hist. Nat. **2:** 209–216. *pl. 8.* 1815.

————, (1815[a] and [b]). Flore Française **2** : p. 277. 1815; **6** : pp. 110–111. 1815.

Clinton, G. P. ('04). Rhizoctonia (Rosette). Conn. Agr. Exp. Sta., Rept. **1904:** 325–326. *pl. 26. f. a–c.* 1904.

————, ('13). Evergreens, damping-off. Conn. Agr. Exp. Sta., Rept. **1912:** 348–349. 1913.

Collinge, W. E. ('12). Root and stem rot (Rhizoctonia violacea Tul.). Second Rept. on Econ. Biol. pp. 46–47. Birmingham, 1912.

Comes, O. ('91). Crittogamia agraria. 600 pp. *168 f.* 1891.

Cook, M. T. and Horne, W T. ('05). Insects and diseases of tobacco. Estac. cent. agron. de Cuba, Bull. 1:1–22. *f. 1–20.* 1905. [See Seed bed diseases, pp. 17–18. *f. 18, c-f.*]

Cooke, M. C. ('04). Another potato disease, "black leg." Gard. Chron. III. **36**: 28. 1904.

Corboz, F. ('00). Le rhizoctone de la pomme de terre. Chron. agr. du Canton de Vaud **1900**: 347–349. 1900.

Cunnigham, D. D. ('97). On certain diseases of fungal and algal origin affecting economic plants in India. Sci. Mem. by Med. Off., Army of India **9**: pp. 102–111. *pl. 1. f. 1–11.* 1897.

Darnell-Smith, G. P. ('14). Potato scab. Agr. Gaz. N. S. W. **25** : 869–872. 1914.

Decaisne, ('37). Recherches anat. et physiol. sur la garance. pp. 55–56. 1837.

Delacroix, G. ('03). Rapport sur une maladie des asperges dans les environs de Pithiviers. Off. Rens. Agr., Bull. Mens. **1903** : 1108–1113. 1903. [Not seen.]

Drayton, F L. ('15). The Rhizoctonia lesions on potato stems. Phytopath. **5** : 59–63. *f. 5. pl. 6.* 1915.

Duby, J. E. ('30). Botanicon Gallicum **2** :p. 867. 1830.

Duggar. B. M. ('99). Three important fungous diseases of the sugar beet. Cornell Univ. Agr. Exp. Sta., Bull. 163: 339–363. *f. 49–63.* 1899.

————, ('09). Fungous diseases of plants. pp. 444–452. *f. 217–222;* pp. 477–479. *f. 239.* 1909.

————, and Stewart, F. C. ('01). A second preliminary report on plant diseases in the United States due to Rhizoctonia. Science, N. S. **13** : 249. 1901.

————, ————, ('01). The sterile fungus Rhizoctonia. Cornell Univ. Agr. Exp. Sta., Bull. 186 : 50–76. *f. 15–23.* 1901. *Ibid.* N. Y. Agr. Exp. Sta., Rept. **19** : 97–121. *pl. 8–9. f. 1–7.* 1901.

Du Hamel du Monceau (1728). Explication physique d'une maladie qui fait périr plusieurs plantes, etc. Hist. de l'Acad. roy. d. Sci. d. Paris **1728**: 100–112. *pl. 1–2.* 1728.

Edgerton, C. W. and Moreland, C. C. ('13). Diseases of the tomato in Louisiana. La. Agr. Exp. Sta., Bull. 142: 1–23. *f. 1–2.* 1913. [See Damping off. p. 22.]

Edson, H A. ('15). Seedling diseases of sugar beets and their relation to root-rot and crown-rot. Jour. Agr. Res. **4**: 135–168. *pl. 16–26.* 1915. [See Rhizoctonia. pp. 151–159. *pl. 16, f. 1; pl. 20–22; pl. 23, f. 1.*]

Eidam, E. ('87). Untersuchungen zweier Krankheitserschceinunger [etc.] Schles. Ges. f. väterl. Cultur, Jahresb. **65**: 261–262. 1887. [Abs. in Bot. Centralbl. **35**: 303–304. 1888.]

Ellis, J. B. and Everhardt, B. M. ('84). New species of North American Fungi Torr. Bot. Club, Bull. **11**: 17. 1884.

Eriksson, J. ('03). Några studier öfver morotens rotfiltsjuka, med särskildt afseende på dess spridningsförmåga. K. Landtbr. Akad. Handl. och Tidskr. **42**: 309–334. *pl. 1. f. 1–4.* 1903.

————, ('03a). Einige Studien über den Wurzeltöter (Rhizoctonia violacea) der Möhre, mit besonderer Rücksicht auf seine Verbreitungsfähigkeit. Centralbl. f. Bakt. II. **10**: 721–738, 766–775. *pl. 1. f. 1–4.* 1903.

Eriksson, J. ('12). Svampsjudkomar å svenska betodlingar. K. Landtbr. Akad. Handl. och Tidskr. **51**: 410–437. *f. 1–9.* 1912. [See Rotfiltsjuka. Rhizoctonia violacae Tul. pp. 421–430. *f. 4–5.*]

———, ('13). Études sur la maladie produite par la rhizoctone violacée. Rev. Gén. Bot. **25**: 14–30. *f. 1–4.* 1913.

Fallada, O. ('09, '10). Oesterr.-Ungar. Zeitschr. f. Zuckerind. und Landw. **38**: p. 13. 1909; **39**: p. 45. 1910.

Frank, A. B. ('96). Die Krankheiten der Pflanzen **2**: pp. 514–520. 1896. [2nd ed.]

———, ('97). Ueber die Ursachen der Kartoffelfäule. Centralbl. f. Bakt. II. **3**: 13–17, 57–59. 1897.

———, ('97a). Ein neuer Rebenschädiger in Rheinhessen. Zeitschr. f. d. landw. Ver. des Grossh. Hessen **1897** (No. 19): 167–168. [Abs. in Centralbl. f. Bakt. II. **4**: 781. 1897.]

———, ('98). Untersuchungen über die verschiedenen Erreger der Kartoffelfäule. Ber. d. deut. bot. Ges. **16**: 273–289. 1898.

———, und Sorauer, P. ('94). Jahresberichte des Sonderaus. f. Pflanzenschutz 1893–1899. [Arb. d. deut. Landw.- Ges. Heft. 5,8,19,26,29,38,50. Berlin, 1894.]

Freeman, E. M. ('08). Diseases of alfalfa. Kan. Agr. Exp. Sta., Bull. 155; pp. 322–328. *f. 38–42.* 1908.

Fries, E. (1823). Systema mycologicum **2**: pp. 265–266. 1823.

———, (1828). Elenchus fungorum **2**: pp. 45–46. 1828.

Fuckel, L. ('69). Symbolae mycologicae. pp. 142 and 406. Wiesbaden, 1869.

Fulton, H. R. ('08). Diseases of pepper and beans. La. Agr. Exp. Sta., Bull. 101: 1–21. *f. 1–15.* 1908. [See Pod rot and stem rot due to Rhizoctonia, pp. 17–19. *f. 14–15.*]

Gandara, G. ('10). Gangrenosis de la raiz de la alfalfa. Mem. y. Rev. Soc. Cient. **29**: 385–388. *f. 14–15.* 1910.

Gloyer, W. O. ('13). The efficiency of formaldehyde in the treatment of seed potatoes for Rhizoctonia. N. Y. Agr. Exp. Sta., Bull. 370 : 417–431. 1913.

Güntz, M. ('99). Beobachtungen über den Wurzeltöter von Klee, Rhizoctonia violacea Tul. Fühlings Landw. Zeit. **48** : 731–732. 1899. [Abs. in Centralbl. f. Bakt. II. **6** : 506–507. 1900.]

Güssow, H. T. ('05). Potato scurf and potato scab. Roy. Agr. Soc., Jour. **66**: 173–177. *f. 3.* 1905.

———, ('06). Beitrag zur Kenntnis der Kartoffel-Grindes. Corticium vagum B. et C. var. Solani Burt. Zeitschr. f. Pflanzenkr. **16** : 135–137. *pl. 8.* 1906.

———, ('10). Problems of plant diseases. p. 70. Ottawa, 1910.

———, ('12). "Rhizoctonia" disease of potato. Canada Agr. Exp. Farms, Rept. **1912**: 199–202. *f. 3.* 1912.

———, ('14). The storage rots of potatoes. An experiment with Rhizoctonia diseases of potatoes. Canada Agr. Exp. Farms, Rept. **1913**: 480–485. 1914.

Hallier, D. E. ('75). Ein gefährlicher Feind der Kartoffel. Oesterr. Landw. Wochenbl. **1875**: 387–388. 1875. [Abs. in Just's Bot. Jahresb. **3**: 228–229. 1875.]

Hartig, R. ('80). Unters. a. d. forstbot. Inst. zu München **1880** : 1–32. *pl. 1–2.* 1880.

Hartley, C. P. ('12). Damping off by coniferous seedlings. Science, N. S. **36** : 683–684. 1912.

————, ('13). The blights of coniferous nursery stock. U. S. Dept. Agr., Bull. 44: 1–21. 1913.

Heald, F. D. ('06). Report on the plant diseases prevalent in Nebraska during the season of 1905. Nebr. Agr. Exp. Sta., Rept. **19**: p. 40. 1906.

————, ('11). Rhizoctonia Medicaginis in America. Phytopath. **1**: 103. 1911.

————, and Wolf, F. A. ('00). Tex. Acad. Sci., Trans. **11**: pp. 31–32. 1900.

————, ————, ('11). U. S. Dept. Agr., Bur. Pl. Ind., Bull. 226 : pp. 39, 40,41,42,43,44,111. 1911.

Hedgcock, G. G. ('04). A note on Rhizoctonia. Science, N. S. **19** : 268. 1904.

Hibbard, R. P. ('10). Cotton diseases in Mississippi. Miss. Agr. Exp. Sta., Bull. 140: 1–27. *f. 1–8.* 1910. [See Damping-off or sore-shin. pp. 17–18. *f. 4.*]

Johnson, J. ('14). The control of damping-off disease in plant beds. Wis. Agr. Exp. Sta., Res. Bull. 31 : 29–61. 1914.

Jones, L. R. ('07). The black leg disease of the potato. Vt. Agr. Exp. Sta., Bull. 129: 101–103. 1907.

Kickx, J. ('67). Flore cryptogamique des Flandres **2**: p. 470. 1867.

Kühn, J. ('58). Krankheiten der Kulturgewächse, ihre Ursachen und ihre Verhütung. pp. 222–228, 228–239, 243–249. *f. 3–22.* 1858.

Laubert, ('06). Bot. Centralbl. **102**: 525–527. 1906.

Léveillé, J. H. ('43). Mémoire sur le genre Sclerotium. Ann. d. Sci. Nat. Bot. **20** : 218–248. *pl 6–7.* 1843.

Lindau, G. ('09). Rabenhorst's Cryptogamen-Flora v. Deutschland, Oesterreich, u. d. Schweisz. 1^9: 683–686. 1909.

Link, H. F. (1824). Hyphomycetes. Linnaeus, Spec. Plant., ed. 4, cur. Willdenow. 6^1 : pp. 119–120. Berlin, 1824.

Lüstner, G. ('03). Beobachtungen über den Wurzeltöter der Luzerne (Rhizoctonia, violacea Tul.). K. Lehranst. f. Wein-, Obst-, u. Gartenbau zu Geisenheim a Rh. **1902** : 200–203. *f. 47.* 1903.

Lyon, T. L. and Wianco, A. T. ('02). Diseases of sugar beets. Nebr. Agr. Exp. Sta., Bull. 73 : 21–23. 1902.

McAlpine, D. ('11). Rhizoctonia rot, or potato collar fungus. Handbook of fungous diseases of the potato in Australia and their treatment. pp. 60–65. *pl. 9–13, 19, 39–43.* 1911. (cf. pp. 75–77.)

McCready, S. B. ('10). Pod and stem rot of beans (Rhizoctonia). Ont. Agr. Coll. and Exp. Farms, Rept. **36** : 46–47. *f. 6.* 1910.

Montagne, C. ('50). Etude micrographique de la maladie du safran, connue sous le nom de Tacon. Soc. de Biol., Paris, Mém. 1 [1849]: 63–68. 1850. [Translation by Berkeley, Jour. Hort. Soc. London **5**: 21–25. 1850.]

Morse, W. J. and Shapovalow, M. ('14). The Rhizoctonia disease of potato. Me. Agr. Exp. Sta., Bull. 230 : 193–216. *f. 61–73.* 1914.

Nees von Esenbech, (1816). Das System der Pilze und Schwämme. p. 148. Wurzburg, 1816.

Nelson, A. ('07). Some potato diseases. Wyo. Agr. Exp. Sta., Bull. 71 : 1–39. *f. 1–11.* 1907.

Norton, J. B. S. ('06). Irish potato diseases. Md. Agr. Exp. Sta., Bull. 108 : 63–72. *f. 1–4.* 1906.

Orton, W. A. ('14). Potato wilt, leaf-roll, and related diseases. U. S. Dept. Agr. Bull. 64: pp. 40–41. *pl. 15.* 1914.

Pammel, L. H. ('91). Fungous diseases of the sugar beet. Ia. Agr. Exp. Sta., Bull. 15: 234–254. *pl. 1–7.* 1891. [See Preliminary notes on a root-rot disease of sugar beets. pp. 243–251. *pl. 3–6.*]

Peglion, V. ('97). Il mal vinato della medica e delle barbietole. Bol. di Entom. Agron. e Patol. Veg. **4** : 367–369. Padua, 1897.

Peltier, G. L. ('14). Rhizoctonia in America. Phytopath. **4**: 406. 1914.

Persoon, C. H. (1801). Synopsis methodica fungorum. pp. 119–120. 1801.

Pethybridge, G. H. ('10). Potato diseases in Ireland. Dept. Agr. and Tech. Instr. for Ireland, Jour. **10**: 1–18. *f. 1–8.* 1910.

———, ('10a). A little known potato disease. Garden **74**: 560. *f. 1.* 1910.

———, ('11). Investigations on potato diseases (second report). Dept. Agr. and Tech. Instr. for Ireland, Jour. **11**: 29–32. *f. 11–14.* 1911.

———, ('15). "Black speck" scab and "collar fungus." *Ibid.* **15**: 513–517. 1915.

Pierson, W. R. ('02). Sterilized soil for stem rot. Gardening **10**: 179–181. 1902.

Potel, H. ('00). Molestias cryptogamicas da batata ingleza e seu tractamento. Bol. da Agr. Estado de São Paulo **1** : 45–48. 1900. [See p. 46.]

Prillieux, E. ('83). Étude sur deux maladies du safran. Ann. de l'Inst. Nat. Agron. **6**: 17–31. *pl. 3–4.* 1883.

———, ('91). Sur la pénétration de la Rhizoctone violette dans les racines de la betterave et de la luzerne. Compt. rend. acad. Paris **113**: 1072–1074. 1891.

———, ('96). *Ibid.* Soc. Bot. de France, Bull. **43** : 9–11. *f. 1.* 1896.

———, ('97). Maladies des plantes agricoles **2** : 144–157. *f. 282–287.* 1897.

———, et Delacroix, G. ('91). Hypochnus Solani nov. sp. Soc. Myc. France, Bull. **7**: 220–221. *f. 1.* 1891.

Prunet, A. ('93). Sur le Rhizoctone de la lucerne. Compt. rend. acad. Paris **117**: 252–255. 1893.

Riehm, E. ('11). Ueber den Zusammenhang zwischen Rhizoctonia Solani Kühn und Hypochnus Solani Prill. u. Del. K. Biol. Anstalt f. Landw.- u. Forstw., Mitt. **6**: p. 23. Berlin, 1911.

Rolfs, F. M. ('03). Corticium vagum B. and C. var. Solani Burt. Science, N. S. **18**: 729. 1903.

———, ('02, '04). Potato failures. Colo. Agr. Exp. Sta., Bull. 70 : 1–20. *pl. 1–12.* 1902; 91: 1–33. *pl. 1–5.* 1904.

———, ('05). (Tomato diseases) Corticium vagum (B. and C.). Fla. Agr. Exp. Sta., Rept. **1905** : 46–47. 1905.

Rostrup, E. ('86). Undersgelser angaaende Svampeslaegten Rhizoctonia. K. Dans. Vid. Sels. Forhandl. **1886** : 59–77. *pl. 1–2.* 1886.

Roze, E. ('96). Observations sur le rhizoctone de la pomme de terre. Compt. rend. acad. Paris, **123**: 1017–1019. 1896.

————, ('97). La maladie de la gale de la pomme de terre et ses rapports avec le Rhizoctonia Solani Kühn. Soc. Myc. de France, Bull. **13** : 23–28. 1897.

Saccardo, P. A. ('99). Syll. Fung. **14**: pp. 1175–1177. 1899.

Salmon, E. S. ('08). Disease of seakale. Gardeners' Chronicle **44** : 1–3. *f. 1–3.* 1908.

————, and Crompton, T. E. ('08). The Rhizoctonia disease of seakale. S. E. Agr. Coll., Wye, Jour. **17** : 348–353. *pl. 21–25.* 1908.

Scholz, E. R. ('97). Rhizoctonia Strobi, ein neuer Parasit der Weymouthskiefer. K. K. Zool.- Bot. Akad. Ges., Verhandl. **47** : 541–557. *f. 1–6.* 1897.

Selby, A. D. ('02). A disease of potato stems in Ohio, due to Rhizoctonia. Science, N. S. **16**: 138. 1902.

————, ('03). A rosette disease of potatoes. Ohio Agr. Exp. Sta., Bull. 139 : 51–66. *f. 1–5.* 1903.

————, ('03a, '06). Studies in potato rosette II. *Ibid.* 145 : 13–28. *f. 1–4.* 1903. [cf. also, Circ. 57 : 1–7. 1906; and 59 : 1–3. 1906.]

————, ('04). Tobacco diseases, bed rot. *Ibid.* 156 : pp. 97–99. *pl. 1.* 1904.

Shaw, F. J. F. ('13). The morphology and parasitism of Rhizoctonia. Dept. Agr. India, Mem. **6**: 115–153. *pl. 1–11.* 1913.

Sorauer, P. ('86). Pflanzenkrankheiten. pp. 354–361. 1886. (2d ed.)

————, ('08). *Ibid.* **2** : 471–474. 1908. (3d ed., revised by Lindau 1908.)

Stevens, F. L. ('13). The fungi which cause plant disease. Rhizoctonia. pp. 406–408. *f. 293–294;* pp. 659–660. 1913.

————, and Hall, J. G. ('09). Hypochnose of pomaceous fruits. Ann. Mycologici **7**: 49–59. *f. 1–8.* 1909.

————, and Wilson, G. W. ('11). N. C. Agr. Exp. Sta., Rept. **1911** : 70–73. 1911.

Stewart, F. C., French, D. T., and Wilson, J. K. ('08). Troubles of alfalfa in New York. N. Y. Agr. Exp. Sta., Bull. 305 : 330–416. *pl. 1–11.* 1908. [See Root-rot and damping off. pp. 392–393.]

Stift, A. ('00). Der Wurzeltödter oder die Rotfäule der Rüben (Rhizoctonia violacea Tul.). Die Krankheiten der Zuckerrübe. pp. 67–72. *pl. 8–9.* Wien, 1900.

————, ('13). Zur Geschichte des Wurzeltödters oder der Rothfäule (Rhizoctonia violacea Tul.). Oesterr.-Ungar. Zeitschr. f. Zuckerind. u. Landw. **42** : 445–461. 1913.

Stoklasa, J. ('98). Wurzelbrand der Zuckerrübe. Centralbl. f. Bakt. II. **4**: 687–694. 1898.

Stone, G. E. and Smith, R. E. ('00). The rotting of greenhouse lettuce. Mass. Agr. Exp. Sta., Bull. 69 : 1–40. *f. 1–10.* 1900. [See A Rhizoctonia disease of lettuce. pp. 16–17. *f. 8–10.*]

————, ————, ('02). Carnation stem rot. Mass. Agr. Exp. Sta., Rept. **14**: 67–68. 1902.

Tassi, F. ('00). Di una nuova Rhizoctonia. Bul. de Lab. ed Orto Bot. Siena **3** : 49–51. *pl. 4, f. A–M.* 1900.

Taubenhaus, J. J. ('14). The diseases of the sweet pea. Del. Agr. Exp. Sta., Bull. 106: 1–93. *f. 1–43.* 1914. [See Root rot. pp. 18–27. *f. 9–11.*]

Tubeuf, K. von ('97). [Trans. by W. G. Smith.] Diseases of plants induced by cryptogamic parasites. pp. 201–202. 1897.

Tulasne, L. et C. ('62). Fungi Hypogaei. pp. 188–195. *pl. 8, f. 4*; *pl. 9*; *pl. 20, f. 3–4.* 1862.

Van Hook, J. M. ('04). Diseases of ginseng. Cornell Univ. Agr. Exp. Sta., Bull. 219: 277–303. *f. 18–42.* 1904. [See Damping off by Rhizoctonia. pp. 289–291. *f. 32–33.*]

Webber, H. J. ('90). Catalogue of the flora of Nebraska. Nebr. State Bd. Geol., Rept. **1889** : p. 216. 1890.

Whetzel, H. H. and Rosenbaum, J. ('12). The diseases of ginseng and their control. U. S. Dept. Agr., Bur. Pl. Ind., Bull. 250 : 1–44. *pl. 1–12.* 1912. [See Damping-off of seedlings. pp. 22–23.]

Westendorp, G. D. ('52). Notice sur quelques Cryptogames inédites ou nouvelles pour la flore belge. Acad. Roy. Belg., Bull. 18^2 : p. 402. 1852.

Winter, G. Die Pilze. [In Rabenhorst's Cryptogamen-Flora von Deutschland, Oesterreich, u. d. Schweiz 1^2 : p. 277.]

Wolf, F. A. ('14). Fruit rots of egg plant. Phytopath. **4**: 38. 1914.

Wollenweber, H. W. ('13). Pilzparasitäre Welkekrankheiten der Kulturpflanze. Ber. d. deut. bot. Ges. **31**: 17–33. 1913. [See Rhizoctonia. p. 30.]